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UNDERREPRESENTATION OF GIRLS AND WOMEN IN COMPUTER SCIENCE: CLASSIFICATION OF 1990S RESEARCH

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ABSTRACT

The proportions of Computer Science (CS) graduates who are women has been declining in the last fifteen years. At a time when the demand for computer programmers and systems analysts has been increasing, why are women becoming a smaller proportion of those enrolling in CS programs? This article presents a categorization by educational stages of the research into this topic, and an evaluation of the generalizability of findings to broader contexts. The categorization shows that the most extensive research on women in computing is done at the post-secondary stage, and uses students as non-randomly selected subjects. These studies are non- comprehensive, but where similar results are found in a number of studies, the findings are supported. The emphasis in research focuses on structural factors at the elementary stage, but by the post-secondary stage the emphasis is more likely to be on social psychological factors.

INTRODUCTION AND STATEMENT OF THE PROBLEM

In Canada, as in other western countries, the proportion of computer science (CS) graduates who are women has been declining in the last fifteen years [1]. Undergraduate full-time enrollments in CS have declined for women, as a proportion of total full-time CS enrollment, from 27 percent in 1982 to 20 percent in 1992. The absolute number of undergraduate females enrolled full time in CS fell from 2,845 in 1982 to 1,764 in 1992. Similar to enrollments, undergraduate

CS degrees granted to women also declined from 26 percent in 1982 to 20 percent in 1991 [1].

At the same time, the demand for computer programmers and systems analysts has been increasing. In the United States, the demand has exceeded the supply in recent years resulting in a shortage of more than 190,000 programmers and systems analysts [2]. The use of computers and computer technology is extensive in both industry and the service sector; both sectors require computer programmers and systems analysts. In Canada, according to results of the Survey on Preparedness of Canadian Business for the Year 2000, there is a projected need for 7,000 programmers to cope with Year 2000 concerns in business, not including governments and other public institutions. This figure underestimates the need for programmers, since it does not include the need for programmers to do other work than that associated with the Year 2000 problem [3].

Government projections indicate that future job prospects for those with CS degrees are good, so much so that the Ontario government wants to double the CS pipeline. The government has budgeted "$150 million over 3 years to double entry-level enrollments in CS and high-demand fields of engineering" [4]. The growth in jobs in the computer service industry is reflected in the increase in total wages paid to Canadian employees in that industry, from $660 million in 1982 to just over $4 billion in 1995 [5].

Given the importance of computer technology for almost all sectors of society, those who create and work on computer programs and systems are in powerful positions, possessing highly valued and specialized skills. This article addresses the question of why women are not taking advantage of this situation. Why are women becoming a smaller proportion of those enrolling in CS programs, and graduating with degrees in CS?

A number of studies have sought to address this issue; each contributes some information toward understanding the complex issues surrounding gender and computer technology, but reviews of this research can lead to conclusions that are misleading in two ways. First, findings are sometimes generalized to females of all ages or education levels, when empirical studies on gender and computing tend to test hypotheses on one age group, or on students at a specific level of education [6]. Second, the methodology and measures used vary widely from a few comprehensive studies using random samples, to small, pilot studies and exploratory research. A comprehensive overview of the research into women and computing must take these factors into account. This article attempts to do that: it brings together the results of these studies to see what general conclusions can be drawn from past research on gender and computing, and defines the parameters for future research into this area. The resulting classification of research (Figure 1) will be useful for academic researchers, education policy makers, and teachers because it shows gaps in past research, evaluates how well-supported the findings are, and establishes what is known about the problem and what is still to be discovered.

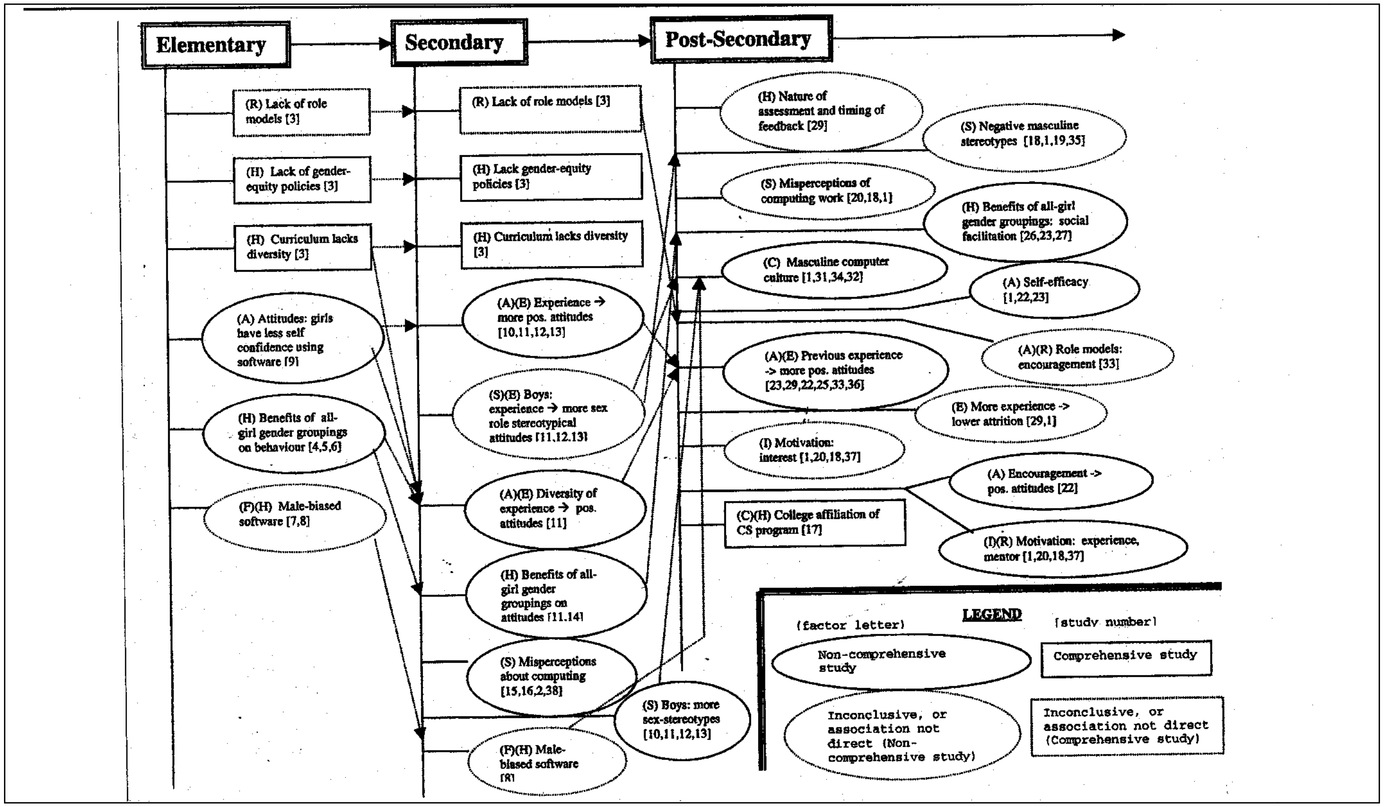

Figure 1. Life stage classification of factors affecting women in computing.

METHODS

This section presents the methodology used to generate the classification model. Research on women and computing is reported in education, sociology, science, and computing literatures. All of these sources were searched for reports of research on women and computing education. To select articles for inclusion in the classification and review, the following method was used. Publications were grouped by four distinct aims: 1) those that publish findings from empirical research into this topic; 2) those that suggest interventions (review and suggestion articles); 3) those that tell about some of the initiatives that have been undertaken to attract and retain more women in CS (report on projects papers); and 4) those that present theoretical approaches to the looking at women and computing.

This article has the specific aim of describing and assessing *empirical* research, so the focus is on those publications with the first aim—reports of empirical research. Only reports of empirical research are in the classification.

Computer education has been in a state of continual change over the last decade, both at the level of policy and in resource allocation, teacher recruitment, and teacher training. Some early research may not be relevant any longer; therefore, although the early research is summarized, the detailed discussion focuses on empirical studies published in the last ten years.

Searching all databases relevant to education, science, computing, and sociological studies of gender and education, and limiting the studies to those that are reports of empirical research published in the last decade on gender and computing in education, thirty-eight studies (see Appendix) fit the criteria for inclusion in this review.

There are two parts to the review. First, a stage classification was constructed showing factors used to explain women's underrepresentation in CS, based on empirical research. By a stage classification is meant a classification that outlines the factors significant to women's computing experiences at various stages in their education. The classification is not a developmental model that traces developmental changes from one stage to the next; rather, it classifies studies by the subjects' stage of education to allow one to look for patterns and changes across the major stages of the educational experience. The relevance of using a life stage perspective for this kind of research is that one can gain a sense of what factors are significant for women over time.

Education is categorized in three stages: 1) Elementary School years (Kindergarten to grade 8); 2) Secondary School years (grade 9 to 12); and 3) Post-Secondary School years. Although there may be a slight overlap with studies of "middle school" level students, these three periods reflect transitions and/or prime decision-making periods of a person's education. Also, most empirical research on women and computing focuses on one of these periods of time, or distinguishes between individuals in these different stages.

I Interest/motivation	**C** Culture (class, lab, and general computer culture)
A Attitudes	**S** Stereotypes/sex role beliefs/ (knowledge of the field)
E Experience	**H** Historical/structural factors
R Role models/mentors	**D** Sex discrimination

Figure 2. Major groups of factors affecting women's computer experiences.

Second, the empirical research that has been done to date was evaluated by categorizing studies into one of two groups: 1) non-comprehensive (preliminary, exploratory, or pilot studies); and 2) comprehensive studies. The non-comprehensive group includes primarily studies with small or non-random samples, qualitative studies, and evaluative reports of pilot intervention projects. While these studies in themselves are not generalizable to the population, they are summarized here to indicate the direction of past research, and to show potentially fruitful kinds of research for the future.

Comprehensive studies are defined as those studies using a random sample and/or a comparison group design for analyzing policy or other data. These studies are more widely generalizable because of the random sampling design. Where several non-comprehensive studies find similar conclusions, they are individually categorized as non-comprehensive, but indicate strongly supported relationships.

Figure 2 shows eight groups of factors that are identified in the literature as important for women's computer experience at various stages of their lives[1]. The empirical research into the effect of these factors on women's participation in computer science will be discussed as the factors are covered in the literature reviewed.

RESULTS

Early Literature on Women and Computing

Research on women and computing before 1990 forms the basis for the more recent research into this topic. Frenkel summarizes the early research [7], pointing to important factors such as the disproportionately negative effect on women of the chaotic state of CS education at pre-college levels [8]. She describes the difficulty of getting appropriate technology and teaching expertise to establish CS in schools. Their inclination to follow rules and procedures means young women in schools suffer more than men during these kind of transition periods [7].

[1]These are the major groups of factors identified by a review of the literature on women and computing education.

The isolation of women in post-secondary computing education meant that women were dropping out of graduate programs, or entering industry, rather than endure the patronizing behavior, doubted qualifications, and invisibility that many encountered in academia [7, p. 37]. In industry, women found similar obstacles. Early research also found that, in some cases, women had problems with foreign professors from countries where women's roles are strictly defined [7, 9].

Problems of access to computers were addressed in early research. Girls in general were found to have less access to computers than boys, both in school and at home. This problem was exacerbated for girls from minority groups, particularly for girls and women of color [10]. Even when technology was available in schools, early research found sex bias in educational computer software [11], and sex stereotypes associated with the hacker culture [11, 12].

Partly because of their lack of access and experience compared to boys, girls generally were found to have less self-confidence with computers [7, 13]. Some research documented discrimination against women by teachers and guidance counselors who advised young women to follow careers in more traditional fields [11]. Girls were also found to attribute successes with computers to luck, and failures to lack of competence, rather than to the successful or unsuccessful use of strategies [14, 15].

The research from the late 1970s and 1980s explores important issues and provides a foundation for the more recent research into women and computing. While some issues have lost some of their salience (for example, curricula are now available), others have been more fully explored in recent years (for example, social-psychological factors). What are the important recent findings for the different educational stages?

Current Literature: Since 1990

The overall classification (Figure 1) presents the factors identified in this article as significant for each of the three educational stages.

Elementary Stage Factors: Comprehensive Studies

Reinen and Plomp report on the Computers in Education study of the International Association for the Evaluation of Educational Achievement (IEA) [16]. Based on a stratified random sample of schools in twenty countries, the study sought answers to three questions: "i) to what degree are female role models offered to girls in the schools; ii) in what way do school policies take gender equity issues into account, and iii) to what extent are gender equity issues dealt with in the curriculum?" [16, p. 353].

Elementary Stage Factors: Role Models—The authors acknowledge that past research into the effect of role models on behavior is not conclusive. It appears that mentoring has a much more positive effect than simply having role models [17]. However, aside from Portugal, the study found that, while there is a majority of female teachers at the elementary stage, the proportions of female computer coordinators and female principals are much lower than the proportion of female teachers. A second, related question investigated in this study examines the extent to which these women actually *act* as positive role models. Male elementary teachers were found to rate their knowledge and skills higher than, or equal to, female teachers at this stage; women experience problems with getting adequate time for, and help with, computer class supervision, whereas men have problems with inadequate computer resources [16].

School Organization and Policy—Reinen and Plomp find, upon examining school organizations and policies for gender equity at the elementary stage, that few schools have a special policy on gender equity (approximately 13 or 14%) [16, p. 361]. Where policies do exist, these most often promote: 1) the training of female teachers in computing; and 2) the selection of women as computer activity supervisors. The authors argue that these most common applications of policy indicate a direction toward increasing role models, rather than toward more direct efforts such as ensuring equal access for girls, or instruction geared to girls' interests.

Curriculum Diversity—Regarding diversity of computer applications, Reinen and Plomp find that, at the elementary stage, the average number of computer applications taught is small, ranging from an average of less than two applications in Japan to about five applications in New Zealand. In Canada (BC), the average number of applications taught is slightly less than four. Applications are measured by the number of different kinds of software taught (e.g., drill and practice, tutorial, word processing, spreadsheets, etc.) [16, p. 361]. Programming is taught in elementary education by about 35 percent of the teachers surveyed without any real evidence that gender is a consideration in the choice of programming language [16, p. 363].

Elementary Stage Factors: Non-Comprehensive Studies

Non-comprehensive studies of gender and computing in the elementary stage have focused on differences in students' use of and reactions to software, and on peer interaction when children are learning in groups at computers. The latter focus considers the effect of same-sex and mixed groupings on computer-related attitudes and achievements of young girls.

Gender Grouping—Three studies examine the effect on learning of different gender groupings around computers [18-20]. Working in same-gender groups appears to benefit girls working on computer tasks. Compared to mixed groups, in all-female groups girls tend to be more verbally active about the task at hand, are more likely to get adequate help when they ask for it, are more positive in their affective comments about the task, and are more likely to have an equal share of control of the computer and mouse. In addition, one study finds that girls are more successful at computer tasks and are motivated to stay longer at the computer when working in all-girl groupings [20]. Measuring motivation by the length of time spent at the computer, this study shows that playing with a partner, and success in the game affect children's motivation to continue playing at the computer [20, p. 4].

The findings are consistent that when girls work in same-sex groups they are more motivated to do computing, they are more assertive about getting help, and they gain more control of the computer. What is not known is whether these benefits lead to a greater likelihood of girls continuing in computer studies through secondary and post-secondary stages of their education.

Software Choice—Several studies of elementary stage computer experience have focused on software or courseware [21-23]. To address the hypothesis that choice of software or courseware in the classroom may be a factor in girls' lesser interest in computing, these studies look at representations of gender in software, educational software design, and the assessment and reactions to computer courseware by students at the elementary stage. They find that educational software is gender biased in favor of boys, and that this bias increases with software designed for upper grades. Ring finds that girls have lower self-confidence than boys using educational software [23].

Although the findings are not generalizable to other educational software, the trend in top-selling programs suggests that throughout the elementary years the programs designed for educational use become more and more competitive and violent, and are increasingly more likely to feature male characters than female characters [22]. These findings suggest the need for further research into the association between the increasing masculine bias of programs and the loss of interest in computing that occurs during the elementary and secondary years.

Summary of Elementary Stage Factors—Research on gender and computing education at the elementary stage has primarily focused on structural factors. Lack of gender-equity policies and lack of diversity in curriculum have been found in comprehensive research ; the connection between these structural conditions and girls' interest and achievements in computing draws on early studies and is not assessed in this research. All-girl groupings at the elementary stage consistently are found to have a positive effect on girls' computer-related behavior.

There is comprehensive evidence of a lack of female role models in computing. The debate on whether simply having more role models would have an impact on girls, or whether being mentored really makes the difference in girls' behavior, and the consistent finding that all-girl groupings benefit girls, suggest the need for further research into role models, mentors, and peer influences at this stage.

Two potentially important factors are lacking in the elementary stage research. The first concerns stereotypes, sex role beliefs, and knowledge of the field. At this early educational stage, what do students know about computing work, who do they see working in this field and being successful, and how is that influencing their interest and motivation to learn and use computers? The second factor pertains to experience. To what extent does experience affect attitudes to computing at this stage? What structural changes can be made to ensure that girls at the elementary stage gain the same computer experience as boys?

Secondary Stage Factors

Secondary Stage Factors: Comprehensive Studies

The comprehensive findings at the secondary stage are similar to those at the elementary stage: schools lack female role models in computing and leadership; they do not provide a diverse, interesting curriculum; and gender-equity policies are rare.

Role Models—Reinen and Plomp find that, as at the elementary stage, the percentage of female computer coordinators in secondary schools is much lower than the percentage of secondary stage female teachers overall (for example, in BC, Canada, female teachers are 37% of the total, while female computer coordinators are 14% of total) [16, p. 358]. Also, similar to elementary education, female teachers at the secondary stage consistently rate their skills and knowledge lower than males do.

School Organization and Policy—Regarding gender-equity policies, as with elementary schools, there are few secondary schools with policies in place, and those schools that do have policies apply them in limited ways [16, p. 361].

Curriculum Diversity—Reinen and Plomp find a fairly low diversity of applications of computers in secondary schools. Slightly better than the elementary stage where average numbers of computer applications by country ranged from 1.5 (Japan) to 5 (New Zealand), at the secondary stage the range is from 2.5 (China) to 7.5 (New Zealand). With the exceptions of New Zealand and Poland (5.5 applications), however, most countries provide little diversity in the applications of computers in secondary schools [16, p. 362].

Non-Comprehensive Studies—Non-comprehensive studies of gender and computing in the secondary stage focus primarily on gender differences in attitudes to computing, software, group composition, and knowledge of the field of CS. As with elementary stage students, studies show that girls at the secondary stage benefit from all-girl groupings for computer work.

Attitudes—The assumption underlying the attitude research is that factors such as self-efficacy, computer experience, encouragement and social support, among others, affect attitudes to computing. Negative attitudes to computing would in turn be associated with a lower likelihood of enrolling in computing courses, or pursuing a computer-related career. Attitude change toward both computing, and women in computing, is considered an important long-term solution to the problem of women's underrepresentation in computer education and work [24].

Several studies find that male students have more positive attitudes to computing than female students [25-28]. Experience with computers and diversity of experience are found to be associated with positive attitudes to computing.

Two cautionary notes with respect to these studies: the first concerns the general difficulty in demonstrating causality, and the second concerns the very different ways that "attitudes to computing" are conceptualized and measured. The studies find correlations between variables such as computer experience and interest in computing, but most do not show whether more computer experience leads to greater interest in computing, or vice versa. Also, the conceptualization and measurement of attitudes to computing vary significantly across studies, as will be seen below.

Four studies examine the effect of computer experience on attitudes toward computers [25-28]. Three of the studies find that boys at the secondary stage have more computer experience than girls and that more experience is associated with more positive attitudes to computing [25, 27, 28]. The fourth study does not include males, but finds, like the others, that more computer experience is associated with more positive attitudes to computing [26]. When prior experience is measured only by "owning a computer," Shashaani does not find an association with students' attitudes, although other studies do find this factor to be significant [25].

The studies do not agree on the issue of people's sex-stereotypes about computing. All studies find that boys are more likely than girls to hold sex-stereotypical attitudes about computing [25, 27, 28], but Levin & Gordon [27] and Durndell et al. [28] also find that for boys, sex-stereotypical attitudes increase with computer experience. Shashaani, on the other hand, finds that as both boys' and girls' experience with computers increases, belief in equality of both men's and women's skill and ability to use computers also increases. This finding is somewhat questionable since, overall, boys report less belief in gender equality than girls, despite having more computer experience than girls. This issue should be explored more fully.

Gender Groupings—Two studies extend the work on gender and attitudes to computing at the secondary stage to see whether single-sex settings or groupings have an effect on women's attitudes to computing [26, 29]. As with the elementary stage, these studies find that all-female groupings benefit women; women are more confident about their abilities with computers, have more sources of help, and gain more diverse experience with computers when in all-women groups or settings.

Jones and Clarke show that girls in single-sex settings have more computer experience and more positive attitudes to computers than girls in co-educational settings [26]. The experience indicators with the strongest associations with positive attitudes are; exposure to a greater diversity of computer tasks and exposure to more sources of computer information. In other words, in single-sex settings female students get a greater diversity of experiences, and more sources of computer-related information; in turn, these "experience" factors are associated with more positive attitudes to computing [26, pp. 58–59]. The benefits of single-sex settings appear to be less related to gender than to women's expanded exposure to computer experiences.

Cooper and Stone examine how gender composition of learning groups affects students' anxiety levels about using computers [29]. As in studies on gender grouping at the elementary stage, these authors found no difference in self-rankings of boys' and girls' own overall knowledge of computers when they were in same-sex groups. However, when boys and girls were mixed, the girls ranked themselves lower and the boys ranked themselves higher on experience and knowledge of computers. Cooper and Stone conclude: "Gender differences in computer experience and knowledge may be a function of the context in which these measures are taken" [29, p. 87].

Perceptions of Computing—To reverse declining enrollments in computer education, some have addressed the possibility that students have misperceptions about computing work. Studies find that many secondary school students believe that computer careers involve programming all day, every day. Interventions communicate the reality that a wide variety of technical and management positions are available to people with computing education, that computer workers move up the job ladder rapidly, and that they command higher starting salaries than graduates from many other fields [30, 31]. One market research study found that if students have negative misperceptions of the computing industry, they are unlikely to choose to study computing. Perceptions of the career that awaits a student after graduation is found to be a strong motivator for studying in any discipline [31].

Software—Chappell's study of math software compares software used at various stages of education [22]. As noted above, at the preschool and elementary stages there is significantly less violence and significantly more female representation in math software than at the secondary stage, on average. The effect of biased software at the secondary stage on women's representation in computing education is not established.

Summary of Secondary Stage Factors—Similar to the elementary stage, structural factors are found to be important at the secondary stage; curriculum diversity and gender-equity policies are lacking at this stage. Studies of all-girl groupings at this stage focus more on their effect on girls' attitudes than behavior. Research on experience is also linked to girls' attitudes; experience is associated with more positive attitudes for girls, and the more diverse that experience, the better. For boys, however, greater experience is tentatively associated with more sex-role stereotypical attitudes. This finding, coupled with students' misperceptions about computing, suggests the need for interventions to clear up stereotypes and provide accurate information about computing work.

Lack of role models remains problematic at the secondary stage, although the same concerns about mentoring as discussed for the elementary stage suggest the need for further investigation of this factor. Gender discrimination in the use of male-biased educational software is more pronounced at this stage, although a direct link to women's underrepresentation in computing has not been made.

Missing at the secondary stage are studies of computing culture, specifically the culture associated with computer classes and labs. At the *post*-secondary stage, women who do take computing identify their secondary school class experiences as influential in their choice. More research is needed to discover what specifically increases women's interest in computing, whether the computer culture encourages or discourages them, and to what extent mentor and peer encouragement affect women's motivation to study computing at the post-secondary stage.

Post-Secondary Stage Factors

At the post-secondary stage there are more publications of research conducted on women and computing than is the case for the other stages. The research is a rich source for hypotheses concerning women's underrepresentation in CS, but only one study fits into the "comprehensive" category [32]. In cases where several non-comprehensive studies arrive at similar conclusions, this suggests more conclusive and potentially generalizable findings. Studies at the university level tend to draw samples from first year student volunteers at a single university.

Comprehensive Studies

College Affiliation of CS Program—Camp compares women's enrollments in CS programs housed in US engineering colleges with those in arts and sciences colleges [32]. She finds that there are significantly fewer women graduating from CS when the department is in an engineering college [32, p. 108]. She argues that engineering culture is even more masculine than CS culture, so when the CS program is associated with engineering it is less attractive to women than when it is associated with less macho cultures.

Non-Comprehensive Studies

Non-comprehensive studies at the post-secondary stage focus on stereotyping, attitudes to computing, gender grouping and social facilitation, experience, culture, and motivation.

Stereotypes—Studies generally agree that computer scientists are stereotyped as male, very smart, antisocial, and content to sit in front of a computer for long hours [33-35]. On the other hand, Colley et al. find no evidence that *women* using computer technology are negatively stereotyped [36]. Durndell and Lightbody find that students' lack of interest in pursuing CS degrees is related to these stereotypical perceptions of computer scientists [34]. Comparing perspectives of women working in computing with those of students, Teague and Clarke find that the reality of computer work is much more people-oriented, diverse, and interesting than is perceived to be the case by students [37].

There is disagreement in the research about stereotypical perceptions of computing work. In interviews with non-CS students, Fisher et al. find CS is believed to be synonymous with programming [33]. Students express negative perceptions of programming work and these beliefs form the basis for a general aversion to the field of CS. Similarly, Durndell finds that business and natural science students perceive computing to involve little human contact, mostly boring keyboard work, and to be restricting and lacking in creativity [35]. On the other hand, Colley et al. do not find that students have stereotypical perceptions of computer-related careers [36]. One exception to the latter finding is that students underestimate the salary levels of computer professionals [38]. Women, more than men, cite the promise of the field as an important motivator in choosing computing careers [33], and therefore the underestimation of salary may impact women more than men.

Attitudes—As was the case at the secondary stage, studies on post-secondary students' attitudes to computing do not use the same attitude measure [39-44]. Different measures and non-random samples may help explain why there are some contradictory findings among studies on attitudes to computing. One study finds no significant effects of computer experience on students' attitudes at the post-secondary stage [42], when computer experience is measured broadly as years of experience. In another study, significant, positive improvements in computer attitudes (computer confidence, liking, usefulness, or anxiety) are found for male and female students given computer training, compared with a no-training control group. No significant gender differences are found in attitudes; the course positively affected both men and women's attitudes [43].

Another study finds gender differences in attitudes to computing do exist, and are strongest in relation to complex computer tasks. Computer experience and encouragement are the most important predictors of computer attitudes, according to this research [40], with females consistently indicating less experience, less encouragement and less positive attitudes to computing. Similarly, Morgan et al. argue that gender differences in early childhood experiences with machines may help explain women's less positive attitudes to computing compared with men [45].

Experience—Prior computer experience is associated with greater success in computer education at the post-secondary stage. All studies indicate that women are less prepared than men entering CS, or they believe themselves to be less prepared. Women's attitudes are more positively associated with any form of previous computer experience than men's [46]. Given the line of logic that experience affects attitudes and attitudes affect behavior, Brown et al. were concerned that attrition from CS programs has to do with lack of experience [47]. Although some studies identify previous experience as an important factor in understanding attrition rates [33, 46], Brown et al.'s attempt to compensate for lack of previous experience by providing students with extra introductory college computer experience finds no reduction in attrition or improvement in grades afterwards, except one year when early feedback was given on students' performance in the course. The costs associated with extra testing prohibited its ongoing use [47, p. 115], but the initial finding is consistent with the notion that women tend to underestimate their abilities [33] and may benefit more than men from extra feedback.

Fisher et al. find an experience-related gender gap in confidence among first year students; males are more confident about their ability to master the course material, see themselves as better prepared for their classes than women, and claim an expert level of knowledge of a programming language [33, p. 107]. For those women who do make it through the first year, however, their confidence levels increase much more than their male counterparts. This supports the conclusion above, that women lacking experience and confidence can catch up. Extra feedback along the way, and staying in the program, may mitigate the negative effects for women of having lower self-efficacy and less computer experience.

Gender Groupings—Less self-efficacy among females may have the positive effect of motivating more group activity and cooperation in group work around the computer, significantly more among groups comprising a majority of females [41]. The social facilitation associated with working in all-female groups also appears to have a positive effect on women's performance at the computer [48]. One study finds, however, that women-only educational settings are perceived by black women and white women differently: white women tend to be more individualistic in their preferred style of learning, black women tend to work more collaboratively and cooperatively [49]. White women tend to explain women's underrepresentation in CS in terms of individual deficits, whereas black women explain it as a power issue. This exploratory study is based on a small sample (11 women) and should be examined further.

Computing Culture—CS culture has been explored as another factor potentially deterring women from entering the field. Although a distinctly masculine culture is found in CS, its effect on women is less clear [33, 50, 51]. In general, it appears that women in CS accept the masculine culture and adjust their expectations and aspirations accordingly, whereas women outside CS are deterred from entering by anticipation of male hostility toward women who do non-traditional work [51]. One study found the prospect of being in all-male work settings to be a greater deterrent for males than females [34].

Masculine values prevail in CS culture. For some women who accept and are comfortable with those values, no negative effect is reported. Women who reject the masculine values and feel uncomfortable with the CS culture accept their own status as marginal; an alternative culture is rarely envisioned or advocated. Bernstein reports on implementation of initiatives to introduce computing culture into the first year CS curriculum, such as discussing computing artifacts (e.g., books, movies, Web sites and electronic lists, etc.) [52]. These initiatives indicate a possible shift from the dominant value of "machine fascination" to a broader fascination that includes exploring the social and cultural impact of computers. Whether the shift becomes widespread and whether it has an impact on enrollments and attrition rates is unknown at this point.

Motivations—Research shows that both male and female students are most strongly motivated to enter CS by their interest in the field [33, 34, 38, 53]. Other motivations to enter CS differ for males and females. Class experiences and a sense of the promise of the field also motivate women to enter CS, whereas games, class experience, and the influence of peers somewhat motivate men [33]. Women are also motivated indirectly by formal experience with CS that stimulates greater enjoyment of computers, whereas men are motivated by self-confidence in their own math abilities [53].

Geenens and Rao compare motivations of sophomores with seniors in a beginning computer course [38]. Sophomores do not agree as strongly as other students that interest is the most important motivator for selecting a major at university. They also are more likely than others to feel that high school experience is sufficient to choose a major [38, p. 26]. Seniors disagree more than the total group that high school experience is sufficient to help students select a university major. These differences in perceptions suggest that the motivation of high school experience diminishes, and interest becomes a stronger motivation as students get more senior in university.

Summary of Post-Secondary Stage Factors

At the post-secondary stage, structural factors are found to be important. Both affiliation of CS with departments other than engineering and all-female groupings appear to facilitate women's enrollment in computing education. Whereas at the elementary stage behavior was studied in relation to all-female groupings, and at the secondary stage the effect of all-female groupings on attitudes were studied, at the post-secondary stage research on all-female groupings focuses on social facilitation. Social facilitation is found to impact positively on task scores, attitudes, and cooperation of women in all-female groups. Non-comprehensive results indicate that the nature of assessment and timing of feedback may be important for reducing women's attrition from CS education. The research on motivation is not conclusive. Students may be motivated by interest, but some students cite other motivations, such as experience and having a mentor.

Stereotypes about CS and sex roles continue to be problematic at the post-secondary stage; however, at this stage the findings are not conclusive. Some studies find that these factors are not applicable to their samples. More conclusive are findings on the masculine computer culture. Non-comprehensive studies report women's perceptions of computing as a male domain. That perception may account for women's significantly lower enrollments in CS departments in engineering colleges.

As at the elementary stage, previous experience is associated with more positive attitudes to computing and may lead to lower attrition. Other attitude research at this stage indicates that women have lower self-efficacy with respect to computing, but are encouraged by having fathers as role models. Role models are not consistently encouraging to women.

Although there are many more studies at this stage than at earlier educational stages, the need for comprehensive research is clear. Many of the studies are carried out on first year students who are convenient rather than representative.

DISCUSSION AND CONCLUSIONS

Three general patterns can be seen in the classification of research. First, more studies use post-secondary students as subjects than students at other educational stages, and more factors are tested at the post-secondary stage. This reflects the use of convenience samples of undergraduate students. Access to subjects affects what is studied and how the studies are conducted. When undergraduate students are used as subjects, the methodology is often to distribute questionnaires and do quantitative analysis of the results.

Second, the vast majority of studies in this area are non-comprehensive. Where the findings are strongly significant, or where several non-comprehensive studies find similar results, these studies provide support for the importance of a factor, and are therefore enclosed in a solid line in the classification. Nevertheless, the findings are preliminary and require further, more comprehensive study.

A third general pattern is the increasing focus of research into social psychological factors at higher stages. There is only one study that identifies girls as having less self-confidence assessing software at the elementary stage. At the secondary stage several studies find a relationship between experience, or diversity of experience, and more positive attitudes to computing. At the post-secondary stage, research explores in more detail the specific attitudes that are affected by experience, encouragement, role models, and structural factors. What motivates and interests women in computing is studied at this stage. In general then, the focus of research appears to move from an emphasis on structural factors at the elementary stage to individual factors at the post-secondary stage.

Structural Factors

The factor designations in parentheses indicate that structural factors have been studied at all three stages. Structural factors include education policy, curriculum, and organization of CS departments (their affiliation and gender groupings). Education policy has been studied at the elementary and secondary stages, but there is no research on this structural factor at the post-secondary stage. Although gender-equity policies have the potential to create opportunities for girls, the Reinen and Plomp study finds that policies are directed more at increasing role models than at increasing access or opportunities for girls [16].

Across all stages, direct or indirect benefits of all-girl groupings have consistently been found. At the elementary stage, all-girl groupings improve task performance and other behaviors, such as asking for help and staying on task longer. Studies at the secondary stage focus more on the effect of all-girl groupings on attitudes, and find that girls' attitudes are more positive in all-girl groupings than in mixed groupings of students. This finding may be indirect through girls' access to greater diversity of experience in all-girl schools. At the post-secondary stage, the benefits of all-girl groupings relate to social facilitation—women encourage one another in their computer work when grouped together.

Although there is no evidence that women will go on to post-secondary education in computing if they have experienced the benefits of all-girl groupings, the immediate benefits for women may encourage them to consider computing as a viable option. For women who are in post-secondary CS education, working with other women provides social support in the program. Women's lower enrollments in post-secondary CS programs affiliated with engineering suggests that women are discouraged from enrolling when the culture of the program is more masculine. Given the consistent finding of benefits for girls and women, efforts should be made to consider how to structure all-girl groupings into computer education. Since CS is a male-dominated occupation, this option should perhaps be part of a larger, mixed curriculum plan for CS education.

Diversity of curriculum is comprehensively studied at the elementary and secondary stages. This research indicates that most countries have little diversity in the computer applications taught to students. Since other studies find that software is male-biased, and that bias may be discouraging to women, curriculum should be reassessed and consideration be given to ensuring that software used is not gender-biased. Further, increasing the applications of computing to better reflect interests of all students should be a priority for CS programs. At the post-secondary stage, the importance of early feedback on performance for women should be studied more comprehensively to identify whether early feedback would have a positive effect on women's confidence and computer attitudes. Would this structural change decrease attrition rates and increase women's grades, as early evidence suggests?

Role Models/Mentors

We know from the research that there are few female role models for girls and women in computing at the elementary and secondary stages. The effect of having few role models on enrollments in CS is unclear, however, especially since there is some confusion in terminology. Sometimes a role model (a person in computing with whom girls and women can identify) is confused with a mentor (someone who takes an interest in a student, provides opportunities for her, and encourages her to continue in computing). The research does show that women are encouraged to enter computing by a positive secondary school experience in computing, which may reflect having had a teacher who mentored them. We also know that women at the post-secondary stage are also encouraged by their female peers. In contrast to these kind of mentoring relationships, role models are not found to be conclusively beneficial for women, since those at the secondary stage with mothers in computer-related work are discouraged from pursuing CS by those role models. Further research into the effect of role models and mentoring is required, especially at the elementary and secondary stages where early mentoring may have a significant impact on girls considering careers.

Culture and Sex-Stereotypes

There are no studies on computing culture at the elementary or secondary stages, but the early development of a masculine culture is reflected in the choice of male-biased software and sex-role stereotyping. While beliefs about the appropriateness of computing for males and females at the elementary stage is not clear, by the secondary stage boys are found to have much more sex-stereotypical attitudes to computing than girls. Several studies find that this difference becomes greater with more computer experience. This suggests that by the secondary stage, girls not only have to deal with being a minority in computing classes, but they also face a majority of students who believe men do computing better than women.

At the post-secondary stage these sex-role beliefs translate into a masculine computing culture that causes women to feel uncomfortable in computer labs and classes. A study of college affiliation of CS programs shows that women are conscious of the masculine culture and try to minimize its impact by choosing schools in non-engineering colleges [32]. Not only are women aware of the masculine culture, but they have negative masculine stereotypes about the men who study and work in computing. The typical stereotype of a computer scientist is not an attractive image for women.

Misperceptions about computing are found at the secondary and post-secondary stages. At these critical stages, when women are choosing their careers, more information and exposure to the reality of computing work is suggested by these findings. Although no studies are available on this issue at the elementary stage, exposing young students to computing work may also be important for attracting more women to computing by motivating them to acquire experience and confidence in computing that is found to be significant at later stages.

Experience, Attitudes and Interest/Motivation

As mentioned above, the research on these individual factors increases at each successive stage. In most studies, no causal relationship is found between attitudes and enrollment in CS. Some studies show that experience, such as an introductory computer course, affects attitudes positively. Another potentially important factor is that women's self-efficacy with respect to computing grows the longer they stay in the CS program. These findings are each supported in several studies.

Where women are encouraged by role models or a mentor, they have more positive attitudes and are more motivated to study computing. Other motivating factors are only considered at the post-secondary stage. Also found to be motivating to women are interest in computing and experience.

From this classification of salient factors at each stage, relevant and targeted action can be taken for social change.

Conclusions

It is evident from the classification that more research is needed before we fully understand why women's proportional representation in CS is decreasing. More comprehensive studies are needed if we are to draw general conclusions from the research. Also, research on computing culture and sex role beliefs should begin at the elementary stages where sex-stereotypical beliefs are forming. Structural changes need to be made based on comprehensive research on policy and curriculum. Further study into how structural, social psychological, and cultural factors interact would demonstrate to what extent changing any single factor would effectively change patterns of enrollment and attrition in CS education.

APPENDIX 1: LIST OF STUDIES IN THE CLASSIFICATION

1. Fisher et al., 1997
2. Craig et al., 1998
3. Reinen and Plomp, 1993
4. Lee, 1993
5. Barbieri and Light, 1992
6. Inkpen et al., 1995
7. Huff, 1996
8. Chappell, 1996
9. Ring, 1991
10. Shashaani, 1994
11. Jones and Clarke, 1995
12. Levin and Gordon, 1989
13. Durndell, Glissov, and Siann, 1995
14. Cooper and Stone, 1996
15. Lynam and Kamal, 1992
16. Teague and Clarke, 1993
17. Camp, 1997
18. Durndell and Lightbody, 1993
19. Colley et al., 1995
20. Geenens and Rao, 1992
21. Teague, 1992
22. Busch, 1995
23. Busch, 1996
24. Pope-Davis and Twing, 1991
25. Pope-Davis and Vispoel, 1993
26. Corston and Colman, 1996
27. Stepulevage et al., 1994
28. Taylor and Mounfield, 1994
29. Brown et al., 1997
30. Bernstein, 1991
31. Rasmussen and Hapnes, 1991
32. Henwood, 1996
33. Sanders and Glapin, 1994
34. Bernstein, 1997
35. Durndell, 1991
36. Morgan et al., 1991
37. Lips and Temple, 1990
38. Teague and Clarke, 1991

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