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Indian Women and Mathematics for Computer Science

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Mathematics, reading, and writing are considered basic skills that students must learn from kindergarten to high school (K-12) in the U.S. As students progress through the education pipeline, physical science courses are progressively introduced as required curriculum. Computer science (CS) is a subject that remains an optional course. With its relative unpopularity [27], CS is further marginalized in high schools. For instance, the College Board [11] discontinued the Advance Placement CS exam in 2009. Further, existing CS courses in high schools focus on graphics, animation, multimedia, robotics, and games, which are considered "frosting" and not "essential" [16, p. 37]. With CS being treated as trivial at K-12, an educational grounding in mathematics can encourage students who are planning to attend a university to pursue a bachelor's degree in CS. K-12 training in mathematics is typically considered a strong predictor of success in science and engineering (S&E) fields.

While all students in the U.S. must enroll in mathematics for most of their K-12 schooling, many are increasingly struggling with the subject. A recent study found that the U.S. is failing to adequately develop the basic mathematics skills of all its students. Students who succeed in mathematics are often either immigrants or children of immigrants from countries where mathematics is highly valued [3]. In 2006, the Program for International Student Assessment by the Organization for Economic Development and Co-operation ranked the U.S. 25th of 30 nations in mathematics achievement [23]. U.S. media outlets and others are decrying the poor preparation of American students in mathematics compared to students in India and China (e.g., February 12, 2006 cover page of *Time* magazine). Most importantly, there is extensive literature showing that mathematics is viewed as a male domain in the U.S. [22], [24], though conclusive evidence to support such stereotypes is often debated.

It has been argued that female students tend to choose careers in the biological sciences, social sciences, and environmental sciences over mathematically-based sciences such as physics, CS, and engineering [9]. For instance, in 2007, women earned a majority of bachelor's degrees awarded in psychology (77%), biological sciences (60%), social sciences (54%), agricultural sciences (50%), and chemistry (50%); they earned a mere 19% of bachelor's degrees in CS [27].

The low number of women in CS education is a critical challenge. Scholars have identified a range of factors that contribute to the underrepresentation of women in CS [2], [10], [32]. Lack of preparation and proficiency as well as a lack of confidence in mathematics have been seen as important factors that cause female students to avoid CS majors.

In contrast to the U.S., CS seems to be a popular major among women in India [35]. Since computer education at the K-12 level is either optional or non-existent in India, and early exposure to computing at home and in school is limited, why do female students think they can handle CS studies once in the CS program at a university? This article addresses that question by examining the relationship between mathematics and CS among female students in India.

Method

This article is based on in-depth interviews conducted by the author with 60 female undergraduates majoring in CS at four institutions of higher education in 2007–2008. The study took place at two engineering institutes and two universities that granted four-year undergraduate degrees in CS. Random sampling was used to select 15 subjects who were in their second and following years of studies at each institution. Once approached, all students participated in the study. The interviews were structured in the sense that certain issues were covered. They were also unstructured in the sense that they resembled private conversations with subjects. Each interview lasted anywhere from less than an hour to an hour and a half. Interviews were recorded, transcribed and inserted in the Nvivo program for data analysis. Findings are reported with interview excerpts to highlight complexity of concepts and by frequency to show their strength.

Mathematics and Computer Science

In most countries, mathematics is required from kindergarten to high school since it is seen as teaching abstract thinking, analytical skills, logic, and problem-solving rigor, in addition to calculation and deduction. The special role of mathematics in education is a consequence of its universal applicability [28]. Among other things, mathematics deals with inference, deduction, and proof. Mathematics builds mathematical models of natural phenomena, of human behavior, and of social systems; and employs data, measurements, and observations from science to discover truth. The discipline relies on logic to seek truth since its domain is not real physical entities, but numbers, chance, form, algorithms, and change. Mathematics is a science of abstract objects [26].

In recent years, however, the centrality of mathematics to CS has been questioned in the U.S. There is a perceived shortage of technical labor in information technology (IT), which threatens U.S. competitiveness in the global economy. An excessive emphasis on mathematics, it is reasoned, will alienate students from pursuing a career in the desirable field of CS. Advocates for women and minorities in CS have argued that too much weight placed on mathematics is used simply as a filter—weeding out students too weak or unprepared to survive [8], [31]. As an example, the Committee on Public Understanding of Engineering Messages and the National Academy of Engineering [12] contend that emphasis on mathematics in marketing engineering may damage rather than increase the appeal of engineering. So, they recommend focusing on collaboration, communication, and teamwork to attract students to engineering fields. In other words, the CS curriculum is seen as sending a chill to underutilized talent pools with its focus on advanced mathematics. Generally, the CS community debates how much and what sort of mathematics their students need.

A few have gone beyond fulfilling labor needs or increasing representation of women and minorities in CS to argue that mathematics is unimportant to CS on technical grounds. For instance, Fant [15] has argued that 1) mathematicians and computer scientists are pursuing fundamentally different aims, and 2) the mathematician's tools are not as appropriate as they once were for questions stemming from computer scientists. According to Fant, the primary questions of CS are not of computational possibilities but of expressional possibilities. Therefore, CS does not need a theory of computation; it needs a comprehensive theory of process expression. The concept of process expression is seen as a common thread running through the various sub-fields of CS.

Do CS students need a strong background in mathematics? An examination of subject matter and the history of CS show that strong mathematical skills have traditionally been valued and rewarded in the field. Historically, CS arose from mathematics and electrical engineering [13]. In the 1960s, CS was understood simply as the study of computers, like botany was the study of plants. By 1970s, the core of CS was seen as the study of algorithms, which were originally studied by mathematicians [20]. In the 1980s, the focal point of CS was the study of algorithms as well as designing and building systems. Since the 1990s, however, the scope of CS has widened. From its theoretical and algorithmic foundations, today CS incorporates cutting-edge developments in robotics, computer vision, intelligent systems, bioinformatics, and other exciting areas [1].

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The core need for CS is discrete mathematics, which includes 1) functions, relations, and sets; 2) basic logic; 3) proof techniques; 4) basics of counting; 5) graphs and trees; and 6) discrete probability. Mathematical tools are used in formal methods of hardware and software design; that is, the precise mathematical specifications are utilized to define a product, and the product's implementation (code) is verified using mathematical proof techniques [20], [34]. Mathematics is also central in verifying performance and security properties [7].

The differences between mathematics and CS are in the subject matter and the approach. Mathematics deals more or less with theorems, infinite processes, and static relationships. CS is predominantly concerned with algorithms, programs, finite constructions, and dynamic relationships [20], [34]. CS is about information and the main vehicle for managing information is programs. Yet, a basic understanding of mathematics is required in all stages of CS development, including design, specification, coding, and verifying the security and correctness of the final implementation. Mathematical skills, therefore, are central to virtually everything in CS, including programming, software system design, applications design, systems analysis, database administration, network administration, and security administration.

The two major professional societies for CS are the Association of Computing Machinery (ACM) and the Institute of Electrical and Electronics Engineers (IEEE) Computer Society. These organizations support the idea that students of CS need a certain level of mathematical sophistication [1]. Mathematical sophistication is the ability to formalize concepts, to work from definitions, to think rigorously, to reason concisely, and to construct a theory [34]. By understanding and applying mathematics, CS students can improve their ability to abstract away from details and to be more creative when solving problems. In the same way that students planning on a career in medicine ought to have a background in biology, or athletes seeking to do well in organized sports need to have physical training, CS students require a solid foundation in mathematics.

Mathematics and Women

There has been a widespread concern about women's participation in mathematics in the U.S. Earlier studies have shown that a lack of preparation and proficiency in mathematics is one of the most important barriers precluding women from S&E careers [17], [36]. Until the 1990s, the National Assessment of Educational Progress mathematics assessment showed that males scored higher than females in grade 12 mathematics. In the early 1990s, the gender gap in mathematics assessment began to narrow, although differences remained in the percentages performing at the proficient and advanced levels of achievement [27]. A recent study found that standardized mathematics scores showed no gap for girls [19]. Yet, U.S. women seem to lack confidence in their mathematical skills when compared to U.S. men. A survey of over 550 students revealed that both men and women had similar math scores on American College Tests (ACTs), but men held more positive attitudes towards their expertise than women [4].

Historically, scholars have highlighted biological differences between men and women to explain the inherent inability of women to understand and embrace mathematics. These scholars see men as naturally superior to women in mathematics. One claim asserts that men are naturally inclined, from birth, to learn about objects and their mechanical relationships. Women, on the contrary, are apparently predisposed toward the affective and emotional aspects of life and relationships. Another claim holds that due to the different genetic composition of males and females, males have a greater command over the cognitive systems responsible for effective reasoning, a prerequisite for mathematics. The final claim maintains that males show a wider spread in mathematical ability genetically [33]. Biological arguments of sex differences such as these seem so persuasive to the general American public that they have been used to assign women an inferior role in social hierarchy [5]. Lawrence H. Summers, then the president of Harvard University, remarked at the National Bureau of Economic Research conference on January 14, 2005, that innate differences between men and women may be one reason fewer women succeed in S&E careers. Brizendine [6], the author of *The Female Brain*, has argued that boys and girls are born with different brains that drive their impulses, values, and their very reality. Accordingly, girls' brains are wired to empathize more than boys' brains.

Biologists such as Linda Birke, Ruth Bleier, Ruth G. Doell, Anne Fausto-Sterling, Stephen Jay Gould, Ruth Hubbard, and Sue Rosser have used science to show that biological differences between men and women do not result in intellectual differences in mathematics or any other S&E field. They have argued that the social behavior of human beings is environmentally based. Fine [18], the author of *Delusions of Gender*, shows flaws in Brizendine's [6] study to argue that bad science is advancing neurosexism. As an example, Fine [18] points out that in countries where women are not considered to be inferior at mathematics, girls perform well in it and are well represented in mathematics competitions.

> The stereotype that boys do better at math is still held widely by teachers and parents.

In the late 1970s, scholars began paying particular attention to the impact of socialization-related psychological attitudes, especially gender-identity issues, on girls' differential achievement and participation in mathematics. The stereotyping of mathematics as a "masculine domain" was viewed as having powerful inhibiting effects on females. Doing well in mathematics could apparently impact a woman's sense of "femininity," creating a problem of "non-congruence" in gender identity for mathematically successful girls and generating anxiety and a "fear of success" [24, p. 461]. The content of mathematics education and practice conveys gender-based stratified systems in which men have the dominant position. The gendered nature of the study of mathematics, then, deters women from pursuing the subject.

Studies have shown that the career expectations of parents, teachers, friends, and students themselves are shaped by the dominant view that mathematics is for males. Parents, who are one of the major sources of educational information and guidance for their children, often do not encourage their daughters to consider mathematics [14]. Mathematics teachers make more eye contact with boys and pay more attention to them than they do to girls in their classes [22]. Friends, if they begin laughing or making fun, affect female students' options to take advanced mathematics courses. Because of socialization pressures, gender-role beliefs, and cultural norms, women themselves end up thinking that men are better in mathematics. "We are living in a culture that is telling girls you can't do math – that is telling everybody that only Asians and nerds do math" (Prof. Janet E. Mertz, cited in [29], n.p.). "The stereotype that boys do better at math is still held widely by teachers and parents. And teachers and parents guide girls, giving them advice about what courses to take, what careers to pursue. I still hear anecdotes about guidance counselors steering girls away from engineering, telling them they won't be able to do the math" (Prof. Janet Hyde, cited in [21], n.p.). Without a pre-college mathematical background, girls may not pursue a major in CS.

Indian Case

Most of the female Indian students we interviewed (77%) identified mathematics as their favorite subject in the secondary school (9th to 12th grades); for the remaining students (28%), science was the second most popular subject. Among 10 students who listed multiple best subjects, mathematics received eight mentions. In contrast, only 3% (2 out of 60) of students listed computers as their best subject. When asked to justify why they listed mathematics as their best subject, these students highlighted the general usefulness of mathematics, the emphasis placed on mathematics at home and in schools, and the mastery needed in mathematics to pursue future S&E studies. One student said, "Some people think math is only for scientists. This is not true. Everyday life revolves around math. So, it is a must subject for everyone." Another student believed that "among all courses [she] took, math stimulated [her] brain in a way no other course did. … Math opened [her] brain to all kinds of knowledge and imaginations." This student endorsed mathematics as it "helped to develop [her] problem solving skills and logical thinking." In this student's words, "I found math to be the only subject where one did not have to do extensive memorization. Biology, chemistry, [and] social studies, they are largely memory-based fields. But, math is a thinking-based field. So, the more you know, the better you become in everything else." This student explained, "My teacher made sure that every student is engaged in learning math. He firmly believed that anyone can learn math, not just smart students." The same sentiment was reinforced at home, "My parents are not well educated. But they always made sure that I finish my math homework. Among all subjects, they mostly talked about math homework and asked questions about my marks."

These students were admitted to their current institutions based on their scores in the institute's entrance exam or a central/state board exam. Once admitted, they were allowed to choose their field of studies based on the marks they received in the exam, and they selected CS. There were many reasons why these students preferred CS over other S&E fields. They saw IT as growing rapidly to permeate modern India, which has created a great demand for the CS. They believed their CS program has dedicated, hard working, intelligent, meticulous, and smart students. Most importantly, students felt that CS is a field where women can excel. They saw themselves prospering economically with a CS degree since the work is high paying, white collar, office-based, and modern. Further, jobs with a CS degree are available in almost every technical industry throughout India. Some students indicated that employment in IT companies is well appreciated at home, and it eases apprehensions their families have about marriage; women who will add income to the household are increasingly desirable. They further thought by being admitted in the CS program, they will be highly respected by faculty, peers, family members, friends, and neighbors. One student said, "All my seniors started telling me that CS is a very good field for girls. Then, I saw my friends going for CS, so I opted for that too. CS is considered the top-most field here at [X]." This student took her father's advice; "My father wanted me to get into CS. He insisted because in this field girls don't have to go into the field. In civil, mechanical, and chemical engineering, girls have to work in the production field." A student generalized, "There is a craze about computers here. They make the work easier. … I had a passion to help my country, do something that will be beneficial to people. I saw computers fulfilling my passion." Another student declared, "Computers are the future of India. So, I chose them." This student was clear, "computers are being used in every field. So, this is the field which can make you earn your bread and butter no matter where you go. You don't have to give up your independence if you move elsewhere after your marriage. So, this is a very practical field."

These students elected to major in CS despite the fact they rarely considered themselves prepared for it at the university level. Only 10% of the students felt fully prepared to study CS at university while 35% of the students felt partially prepared. Over 50% of the students responded that their secondary school had not prepared them to study CS at university. Typically, their secondary schools did not offer computer classes; if they did, these classes were poorly offered. A student said, "Actually our college did not have any concept of CS. They only had some concept of computers. So, they just taught us how to sit on a computer, work on a computer. That is all. So, when I came here, I had no knowledge as to what CS was all about." Another said, "I did take a computer subject in the 10th [grade]. It was very short and concise. It did not teach anything about CS. Then, I did not touch a computer when I was in the 11th and 12th [grades] because entrance exams are very hard. It is like a rat race. Every one prepares for these exams wholeheartedly. So, there was no time for computers." This student resented her secondary school

Jobs requiring a CS degree are available in almost every technical industry throughout India.

CS experience, "I did not have computer classes at least in my [secondary schools]."

Students' responses about the lack of CS studies in secondary schools are not surprising considering the status of computer resources in their schools. About 32% of the students reported that either their secondary schools had no computer facilities, or that they had no access to any available computers. The remaining 68% of the students noted that their secondary schools had computers, but these students did not agree on the quality of the available facilities or their access to them. Generally, students complained about low computer to student ratios, limited access to computer labs, a lack of advanced software or applications, electricity fluctuations, and slow Internet access. One student stated, "There were no computers in the 10th [grade], not even in the 11th and 12th [grades]." If computers were there, "There was no Internet, very few software," which this student disliked. One student complained, "We had a computer lab, which was only open during the computer class. We could not do anything by ourselves." Another student acknowledged, "Our school had a computer lab for students who took a computer subject. But, it was not sufficient. Many students were using it at once. So, most of the time, you get to watch what others were doing. You do not get to put your hands on them." The same was conveyed by this student, "They had some computers. You have to make a line and wait for your turn. If there was a power cut, you missed your turn." One student generalized, "It is absurd to think about CS in schools unless you have a computer, computing resources, software, and connectivity. Though principals and teachers believe they need to have these, they do not have money to buy them."

Considering these students had limited use of computers at home and in schools, and their secondary schools did not prepare them well for the CS study at the university level, it is important to investigate: what made these students believe that they could successfully finish a CS degree? Merely enjoying CS does not guarantee success in the field. Almost every student linked their strong training in mathematics with their enthusiasm to succeed in CS. Those students who only felt that their secondary school partially prepared them for CS at university mentioned limited training in CS as well as a strong foundation in mathematics. The minority of students who felt fully prepared for CS lauded their strong training in both computers and mathematics. As one student said, "I did not take a computer subject in my school because I wanted to become a doctor. But, my school taught me basic concepts of math, which made me rather analytical to handle CS." Another student said, "I did not know computers in my school. But, they prepared me in mathematics. That knowledge helped me to understand CS better now." This student acknowledged, "I was not exposed to a computer at all. Still, I am doing fine in CS because I was prepared in math and physics." One student elaborated, "Math gave me knowledge and critical understanding of basic concepts and principles. Because of math, I learned how to reason to solve a problem, which method to apply to solve the problem, how to articulate the problem logically, what steps to follow and in which order to tackle the problem, etc. These are the keys to understanding the CS."

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If students feel they cannot succeed in the CS program, they will try to avoid disappointing results by finding alternatives. Only 10% of the students interviewed had considered changing their major from CS. The remaining 90% were evidently confident in their major decision. The advantages, prospects, and freedom they could gain from a CS degree encouraged the vast majority to not consider a future away from CS. Those students who did consider other options had no CS experience before university, making their coursework seem somewhat bewildering. After this first year of doubt, however, all of these initially unsure students gained confidence in their ability to complete their degree in CS. As this student acknowledged, "In the beginning, I found CS rather hard. I used to get disheartened. I thought maybe I should change it to something else like civil engineering. But, then I thought nothing is going to be easy. There is going to be a problem in all branches. So, I decided to stick to CS. And, I am glad I stayed in CS." A similar message was given by another student, "I considered changing it in the first year because I did not have a background in CS. But, this was the case with everyone who did not have any background in CS. At that time, I thought perhaps I should do biotechnology because I had knowledge of biology. But, now I thank God that I stayed in CS because it has a great scope." This student was firm, "No. I always wanted to do well in CS. I don't want to go to another field." Said another student, "No. I do not want to change my study. I enjoy CS a lot."

Confidence in Mathematics

Attitudes toward mathematics and gender-identity conflicts are seen as one of the main barriers to girls' achievement and participation in mathematics in the U.S. There is a general perception that males do better than females in mathematics. In American schools, the intellectual environment propagates the stereotype that mathematics is a higher-order discipline for males. It is often said that males and females have different mathematical abilities; although females do well in mathematics, males tend to outscore females on standardized tests. Most importantly, females seem to have less confidence in their mathematics abilities and do not show as much interest in careers requiring mathematical skills than males do.

In contrast, the case study of female students in India has shown that gender does not seem to play any role in acquiring mathematical and problem solving skills. Female students take courses in mathematics, perform well in them, have confidence in their abilities, and show interest in careers that require mathematical skills. By excelling in mathematics, female students demonstrate their smartness and intelligence. Those who do not perform well in mathematics consider taking the medical line (i.e., medicine, biology, or chemistry). If they are unable to do well in mathematics and biology, then they consider taking the art line (i.e., humanities, social sciences, languages, or business). In India, arts, humanities, and social sciences emerge as fields that are for male and female students who are supposedly "not" good in mathematics and biology related fields. This suggests that male success in mathematics is not due to an intrinsic interest for boys. Similarly, there is no biological difference between boys and girls that allow boys to do well in mathematics. Instead, hard work is seen to solve scientific and technical problems for both sexes.

A question of importance is why mathematics does not appear as a male domain in India considering the Indian social context. India' social system remains "patrifocal" [25]. Under the patrifocal system, females are subordinated to family; inheritance is patrilineal; residency is patrilocal; family roles are differentiated along gender lines; marriage is controlled by family; and women are expected to practice chastity, domesticity, and obedience. Patrifocality results in a strong preference for sons over daughters. This study has not dealt with how mathematics is taught in schools in India. There is a need to study both the substance of mathematics and teaching methods in India.

The case study of Indian female students provides convincing arguments for stronger mathematical skills in CS. The female students interviewed believed their strong training in mathematics played a vital role in their enrollment and persistence in the CS program. Even when they had little exposure to the computer and computing, their comfort level in the CS program was attributed to their strong background in mathematics. If they are in CS at the undergraduate level, it means they are good at mathematics. The ability to understand mathematics and the confidence that goes with this comprehension helps women to both to succeed in CS courses and to stay in CS if, during their study, they stumble in some courses. Mathematics enhances self-confidence, and instills in women a "you can do it" attitude. This goes against proposals in U.S. bodies that mathematical skills need to be de-emphasized while promoting CS to attract more women. The case study of female students in India suggests that this may be the wrong approach if the goal is to attract women who will do well in a traditional CS undergraduate program. In fact, it may be even harmful because if during their studies, they are unable to succeed because of deficiency in mathematical ability, it is likely to be extremely discouraging to them and they are likely to feel cheated.

An issue of importance is what specific mathematical courses should be emphasized for CS. The case study of Indian female students in CS highlights that mathematics courses inspire rigor, logical thinking, analytical skills, and problem solving abilities in students. In other words, specific topics in mathematics are not as important as having maturity in mathematics. These students believed they were able to be creative in their approaches to CS because of their background in mathematics. Familiarity with mathematical thinking seems to have prepared these female students for all stages of CS.

Early exposure to computers is seen as essential to generate an interest in education in CS at university level in the U.S. In fact, the term "digital divide" highlights the disparity between those who have full access to IT and those who do not. The digital divide is seen as a symptom of socioeconomic status, income, educational level, age, geography, and so forth. Scholars, educational leaders and policy makers have focused their attention on IT in schools and trained IT teachers because better resourced schools, it is argued, are more likely to provide their students with regular computer access; and teachers with skills to use IT technology effectively are likely to increase their students' CS abilities. The case study of female students in India has shown that in some sense, having limited access to computers at school or home, or having little prior experience in programming are not determining factors in the long-term study of CS. This is not to suggest that having access to computers in school and/or home is irrelevant in India and elsewhere, only that it need not be a major issue in the under-representation of women in CS.

CS Careers Alternatives

A CS career can be viewed as a kind of "liberation theology," as it enables Indian women coming from traditional households to work in challenging high-skilled jobs in a less threatening environment, as well as earn financial independence. CS also offers women an alternative to medicine and a higher salary compared to disciplines with less job opportunities. Jobs with a CS degree are available in many industries, both private and public, including non IT industries. Furthermore, earning a high salary can have many benefits for a woman in a traditional family. Instead of being pushed into a marriage and/or having children, the promise of a stable financial situation can help women persuade their family that a career in CS would be beneficial. It might be possible to argue that a CS career is especially attractive to women as it does not require dirtying your hands during field work or laboratory work. Unlike in other natural science fields, such as physics, chemistry, and biology, CS enables workers to bring the laboratory home on a laptop, USB and via an Internet connection.

To sum up, the case study of female students in India has shown that because they perform well in mathematics, they have high self-efficacy for enrolling and remaining in CS. The new domain of CS builds on prior skills in mathematics. This suggests that CS and mathematics share skills. There is a need to carry out a comparative study of how mathematics is taught to girls and boys in the U.S. and India in order to understand issues related to gender and mathematics.

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