Why Women are Avoiding Computer Science in North American Universities:

Literature Review and Analysis

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Abstract

This literature review investigates the underrepresentation of women within CS, specifically focusing on the perceived gap between male and female enrolment in university CS courses within North America. The paper examines the recruitment of young women in the North American K-12 educational system, explores the influences that affect women's choices in enrolling in CS, and looks at evidence of successful recruitment efforts in high schools. Possible solutions to this problem are discussed, as well as potential benefits of the study to the province of British Columbia.

Keywords: Computer Science, Women, North America, Enrolment

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Introduction

Women were among the first pioneers of the programming age. Women like Ada Lovelace, often considered the world's first computer programmer; Jean Bartik, who together with a group of women programmed one of the world's earliest electronic computers; and Grace Hopper, who invented one of the first programming languages (Isaacson, 2015). These women were part of the Computer Science (CS) revolution, and yet the average student most likely won't recognise their names, even if they study CS (Sydell, 2014).

This underlines a worrying trend that has been affecting the CS community for the past few decades – every year there are fewer and fewer women interested in CS (Beyer, 2014). In fact, the proportion of female students graduating in Computer Science (CS) in North America has stayed consistently low (below 20%) for the past ten years (Zweben & Aspray, 2004; Zweben & Bizot, 2015). The most recent survey indicates that females only made up 14.1% of total CS bachelor's graduates in 2014 (Zweben & Bizot, 2015). This is alarming when we consider that women made up between 34 – 40% of CS graduates in North America over twenty years ago (Horn, Premo, & Malizio, 1995; Statistics Canada, 2016). The problem of female underrepresentation within CS is a serious issue that has been under discussion for a long time in the academic community, particularly since the seminal work *Unlocking the clubhouse: Women in computing* was published (Margolis & Fisher, 2002). Margolis & Fisher took a detailed look into the influences and turning points that combine to extinguish female interest in CS. Most importantly, they showed how certain interventions implemented at Carnegie Mellon University brought about a marked increase in female enrollment in CS (from 7% to 42% within 5 years) (Margolis & Fisher, 2002). However, even though this work garnered much attention in the academic community, there does not seem to have been much improvement in the representation of females in CS – a problem highlighted by the fact that recent female CS enrolment in North America was only at 15.3% (Zweben & Bizot, 2015).

In my own university, the University of British Columbia, the proportion of female undergraduates enrolling in CS majors in the last year was only 22.1% (UBC Department of Computer Science, 2016b). Even though the actual number of women taking CS has increased over the past twenty years, this is true for almost every other subject as the total number of people attending university has increased (National Science Foundation & National Center for Science and Engineering Statistics, 2015; Zweben & Bizot, 2015). However, the proportion of women with bachelor degrees in CS has decreased over the same twenty year span (National Science Foundation & National Center for Science and Engineering Statistics, 2015). This apparent underrepresentation of females within CS becomes more evident when we consider that for the past twenty years more women have been enrolled at universities than men (Snyder & Dillow, 2015; The Association of Universities and Colleges of Canada, 2011). These figures indicate that female underrepresentation should still be a major concern within the CS community, and warrants further research.

My goal is to investigate the underrepresentation of women within CS, specifically to examine the possible factors for the perceived gap between male and female enrolment in CS within North America. I will review the literature to investigate issues surrounding female interest in CS, how this relates to CS undergraduate enrolment, and what is or could be done to narrow the gender gap. Specifically, I will focus on what is being done in the North American K-12 educational system, as it seems that too few studies focus on this aspect of the CS education pipeline (Simard, Stephenson, & Kosaraju, 2010). This issue is very relevant to British Columbia (BC), as there has just been an announcement that computer coding will be added to the BC K-12 school curriculum (Silcoff, 2016).

In this literature review I will first provide definitions I will be using, explain the method behind the review, and describe the theoretical framework which will inform my study. I will then provide an argument to justify why the underrepresentation of females in CS is a problem worth investigating. Subsequently, I will explain why I am narrowing the focus of my research to the recruitment of females into CS, and not their retention. I will look at the state of CS education in high schools, after which I will discuss the influences that affect women's choices in enrolling in CS, and provide evidence of successful recruitment efforts in high schools. I will compare and contrast the CS recruitment problems faced by North America to other countries, and will look into proposed solutions that have the potential to solve this issue. Finally, I will conclude with a summary and elaborate on the purpose and potential benefits of my study.

Definitions

Before I discuss the literature under review, it is important that we first clarify certain terms that will be used throughout this paper, namely Computer Science (CS), North America and Female/Woman.

Computer Science

The field of CS has been evolving rapidly over the past few decades, and has made it difficult for both educators and computer scientists to agree on a single, unified definition of the discipline (Gal-Ezer & Stephenson, 2010). In fact, many schools, colleges and universities have varying definitions of CS. Therefore, before any further discussions are to take place concerning the underrepresentation of women in CS, it is important that we have at least a general definition of the field that satisfies most cases.

One of the most useful definitions of CS, particularly for high school educators, has been provided by the Association for Computing Machinery (ACM) Model Curriculum for K-12 Computer Science. They define computer science as *"an academic discipline that encompasses the study of computers and algorithmic processes, including their principles, their hardware and software designs, their applications, and their impact on society"* (Wilson, Sudol, Stephenson, & Stehlik, 2010). Under this definition, CS can be seen to span a wide range of computing endeavours, including "programming, hardware design, networks, graphics, databases and information retrieval, computer security, software design, programming languages, logic, artificial intelligence, the limits of computations, applications in information technology and information systems, and social issues (Internet security, privacy, intellectual property, etc.)" (Gal-Ezer & Stephenson, 2010). Consequently, it is the definition I will be using throughout this paper.

North America

I use the term ‘North America’ to describe the two countries of Canada and the United States. I do recognize that Mexico forms a large part of North America, but I believe that Canada and the United States have very similar cultures and for convenience I have decided to use the term ‘North America’ to describe their combined culture.

Female/Woman

I use the term ‘female’ and ‘woman’ interchangeably. In both cases I refer to the female gender, and not the female sex. Gender refers to the socially constructed roles that a given culture or society delineates as masculine or feminine, while sex refers to the biological and physiological differences between people. However, I recognise that in most studies and data gathering, female gender and female sex are usually considered synonymous. In addition, there is no inclusion of people of indeterminate gender, those who identify with both genders, or intersex individuals. Unfortunately, as my research will depend on a large number of studies, most of which only recognise female and male genders, I did not feel that I could be inclusive of all the different representations of gender in my research.

I have also made the personal choice in my research to use the term “women” or “young women” for female students in both high school and university. As a feminist in today’s society I believe that the term “girls” is infantilizing and diminishes women both intellectually and professionally.

Method

To perform this literature review I used the University of British Columbia Library online resource (www.library.ubc.ca), the Education Resources Information Center (ERIC) database (eric.ed.gov) and Google Scholar (scholar.google.ca). I used the search terms “women”, “female”, “computer science”, and “enrolment” to obtain a multitude of search results. I sorted through research papers based on relevance to the study (with more focus on women in high school or first-year university), age of the study (papers older than 10 years were only included if they were seminal pieces), location of the study (mostly papers from North America) and if they were from a reputable source (peer-reviewed). Over 80 papers were found using this method, and have been included in this literature review.

Theoretical Framework

I believe that it is important that I provide a brief description of the learning theory that will be informing my views of this issue. The theoretical framework that I have selected for my study is based on Vygotsky’s sociocultural theory, which describes learning as cognitive development through social interaction (Vygotsky & Cole, 1978). Vygotsky states that individuals learn on two levels, first on the social level between people, then on the psychological level within the individuals themselves. Consequently, I argue that if cultural and social circumstances are unfavourable or biased against a group of individuals, the first social level of learning will be disrupted and will obstruct their future cognitive development. My research will focus on exploring the development of favourable cultural and social conditions for women so that they are encouraged to embrace CS.

Research Context

Since my research question is concerned with exploring the reasons behind the low female enrolment in postsecondary CS courses within North America, I focused mostly on research concerned with high school students in Canada and the United States. Most of the literature I reviewed was situated in North America, since I am at a Canadian University and most of my data was accessed through either Canadian or United States databases. However, I will also draw upon literature from other countries outside of North America in order to compare and contrast similar issues that they have regarding women in CS, and to demonstrate how some cultures have overcome the stereotype of CS as a male-dominated society.

I will not focus on the different sociocultural backgrounds or ethnicities of the female students in the literature, since my main focus will be on the causes of the differences between male and female enrolment in CS education. However, I do recognize that this enforces limitations on my research as I am lumping all women together into one group. I also recognize that there is literature that discusses differences in the interest in CS between females of differing social classes, ethnicities and socioeconomic backgrounds. However, that is not in the scope of this research paper.

Why is Women's Underrepresentation a Problem?

It is important to discuss why low representation of women within CS is an issue worth researching. In other words – why should we care? Here I will first discuss why CS education is important in our current society, and second I will examine the reasons why gender equity in CS is so critical.

The Importance of CS Education for All

The role of computer science in society has shifted significantly over the past few decades (Simard et al., 2010). Due to the rapid advances of computing technology, people's interactions with the world are becoming inextricably linked with computers and similar technology. CS education, therefore, enables students to be educated users of this technology, a fundamental twenty-first century skill (Gal-Ezer & Stephenson, 2010; Simard et al., 2010). As more jobs require interaction with computers, CS education will empower students both economically and professionally. By educating students on the fundamentals of CS, we are preparing them for interacting with the real world in which they live.

CS education involves far more than just programming. It is strongly based upon the higher tiers of Bloom's cognitive taxonomy (Bloom, 1956), involving skills in design, creativity, problem solving, collaboration, and critical thinking (Simard et al., 2010). These are skills that are relevant to all students, regardless of their fields of study. Thus it is no surprise that progressively more people require a deep understanding of computing to succeed in a wide range of careers (Stephenson & Dovi, 2013). Art, entertainment, communications and healthcare are just a small sample of the types of industries that rely on an understanding of CS. So while it is considered critical that students have literacy in reading, writing, mathematics and science, the same should apply to computer science. To be a well-educated citizen in today's computing-intensive world, students must have a basic understanding of CS (Simard et al., 2010).

All these arguments provide a strong case for the importance of CS education in North America, and how vital it is to make it available to all members of our society. Therefore it is disturbing to see that the distribution of women in CS education and occupations is so disproportionate to that of men.

Why Gender Equity in CS is So Critical

Women are just as capable as men when it comes to academic performance in CS courses (Beyer, 2008), and have no significant differences in their grades (Beyer, 2014). Therefore it seems that the underrepresentation of women in CS is not due to their lack of ability. In *Unlocking the Clubhouse*, Margolis and Fisher exposed the systemic underrepresentation of women in computing and how CS was a "boy's club" that perpetuated the message that women were not welcome in this field (Margolis & Fisher, 2002). Many of the arguments they made still apply today, almost fifteen years since the book was published.

First and foremost, this issue is one of social justice and denial of equal opportunities to women. This does not mean that the number of men and women in CS needs to be balanced at all times, indeed this is not a feasible way to enforce social justice. What is important is that women are given the same opportunities and encouragement as men to pursue CS, and the significantly low numbers of women enrolling suggest that this is not currently the case.

In addition to the fight for gender equality, there are many additional reasons for the need for more women in CS. Even though there is still a gender wage gap in the CS industry, women who graduate with CS degrees earn more than women who have other majors (Corbett & Hill, 2012; Weinberger, 2006). In fact, CS occupations are some of the best-paying jobs for women not just after graduation, but throughout their careers (Corbett & Hill, 2012). With fewer women enrolling in CS, many of them are missing out on this potential income.

The North American computer profession industry is projected to undergo rapid growth through 2020, which may result in a shortage of qualified CS labour (Lockard & Wolf, 2012). In fact, it seems that Canada is already experiencing this shortage (Faisal et al., 2015). According to the U.S Department of Labor, CS-based occupations are projected to increase by 18% from 2012 to 2022 (Bureau of Labor Statistics, 2013). Thus, increasing the representation of women in CS could have a direct positive impact on the North American economy.

It has also been shown that gender diversity within business is associated with increased sales revenue and greater profits (Barta, Kleiner, & Neumann, 2012; Herring, 2009). The quality of results achieved is enhanced by the diversity of the individuals involved in the business (Eney, Lazowska, Martin, & Reges, 2013). As women bring different thoughts, perspectives and innovations to the table, they can enhance an organization's creativity, problem-solving and performance (Beyer, 2014; Herring, 2009). Therefore, encouraging more women to consider CS as a career could positively impact businesses and industry.

It is also my personal belief that the CS environment is a place for creation and self-expression, and that by excluding women from CS we are depriving them of this unique enriching experience. I believe that these reasons are more than enough to warrant more research into the underrepresentation of women in CS.

Research Focus

There has been ample research that looks at the retention of females within CS once they have entered university (Biggers, Brauer, & Yilmaz, 2008; Chowdhury, Jackson, & Bergen, 2008; Powell, 2008; Varol & Varol, 2014). Many of these studies are interested in investigating the ‘leaking pipeline’ problem. This problem, which has been observed in most industrialized countries around the world, is defined as follows: in every step of a woman’s educational career (e.g., B.Sc., M.Sc., Ph.D., Assistant Professor, Professor) there is a biased selection of men over women, resulting in an increasing underrepresentation of women in higher academia (Blickenstaff, 2005). However, it has been shown that there is a greater “pipeline leakage” in fields such as social science and life science, in which women are more established, than in math-intensive fields, such as CS, in which they are underrepresented (Ceci, Ginther, Kahn, & Williams, 2014). In fact, the number of female Ph.D. CS students in North America has actually increased over the last ten years, despite the decrease in bachelor graduates (Zweben & Aspray, 2004; Zweben & Bizot, 2014).

This suggests that current barriers to women’s representation in CS are rooted more in pre-college factors, and not in “leakage in the pipeline” once they have entered college. This is supported by research which shows that students’ attitudes towards CS are set early on during their middle school years (Bruckman et al., 2009; Zarret, Malanchuk, Davis-Kean, & Eccles, 2006), that early exposure to CS is vital in affecting students’ intentions in choosing CS as a path in higher education (Armoni & Gal-Ezer, 2014; Eney et al., 2013), and that a key factor to promoting greater gender diversity in the field is encouraging women to take CS courses early on in their academic career (Redmond, Evans, & Sahami, 2013). Therefore, I decided that the focus of my research should be on exploring why so few women enrol in CS courses, and what impacts their decision to enrol before they reach post-secondary education. To begin, I will first investigate the current state of CS in North American high schools.

Computer Science in High Schools

CS is not considered a core academic course within the United States school curriculum (U.S. Department of Education, 2015). Canada does not have a nationwide curriculum, but according to all indications, as of the time of writing, CS is not a core course in Canadian schools (British Columbia Ministry of Education, 2015; Government of Alberta, 2015; Ontario Ministry of Education, 2015). However, there has been recognition amongst Canadian provincial governments that CS plays an important role in education, highlighted by a recent announcement that BC plans to add computer coding to their K-12 school curriculum in the next three years (Silcoff, 2016).

There are Advanced Placement (AP) exams in CS that are offered in both the United States and Canada, but these are not standard across schools, states or provinces (The College Board, 2014b). Since CS is not considered a core academic subject, this perceived lack of importance has impacted CS education at district and school levels (K. Lang et al., 2013; Stephenson & Dovi, 2013) and has resulted in difficulties for teachers trying to get certified to teach CS, as well as a general lack of CS standards.

Certification of CS Teachers

The CS certification process presents a lot of challenges for many prospective high school teachers, particularly in the United States. Many states do not have clear licensure standards or requirements for teachers who wish to teach CS in high schools, and there is much confusion as to what CS is and where it fits into K-12 academics (K. Lang et al., 2013; Stephenson & Dovi, 2013). Additionally, there are few universities that offer CS-specific teacher education programs, which means that many prospective teachers do not have access to this knowledge within their state (K. Lang et al., 2013; Simard et al., 2010). In many places where teacher certification systems exist, they are often completely disconnected from teaching and learning requirements within the discipline, and in some cases there are specifications that make it almost impossible for prospective teachers to meet the certification requirements (Stephenson & Dovi, 2013). Even the University of British Columbia, one of the biggest producers of teachers in BC, does not have a CS teacher certification program. This indicates a worrying absence of standards in the CS education community.

Lack of Standards in CS Education

There is deep and widespread confusion in most states and provinces as to what exactly constitutes CS education, and how to differentiate between this and information technology education, or just technology education (Stephenson & Dovi, 2013; Wilson et al., 2010). This confusion surrounding CS education has resulted in a lack of focus on professional development programs for CS teachers and research initiatives in CS education (Simard et al., 2010). Because CS education is not a priority for many states and provinces, it is considered an elective subject in most schools in North America. This is important, as elective courses (and their corresponding teachers) are the last to be given any resources by schools or governments (Wilson et al., 2010). Elective subjects are also less likely to be offered in schools, which means many schools do not offer the subject at all, while schools which do are less likely to hire teachers who are specifically prepared to teach CS, resulting in poor-quality CS courses (Armoni & Gal-Ezer, 2014; K. Lang et al., 2013). Many of these teachers are required to teach other subjects besides

CS, and since CS is not seen to be vital to students' academic success, these teachers do not have the time or the curriculum resources for good CS teaching (Simard et al., 2010). This results in CS courses which are more likely to teach skill-based aspects of computing, and not focus on the conceptual aspects that provide the foundation for innovation and deeper study in CS (Wilson et al., 2010).

In addition many states do not allow CS courses to be counted towards student graduation requirements, resulting in fewer students taking CS (K. Lang et al., 2013). Moreover, there are currently no states or provinces that require CS as a condition of a student's graduation, despite the fact that many broad-based education studies have indicated that students should be required to take some CS in high school (Stephenson & Dovi, 2013; Wilson et al., 2010). The lack of standards in CS education has inspired a number of different initiatives aimed at remedying this situation.

Efforts to Improve CS Standards in High Schools

There have been many efforts to improve upon the current state of the CS curriculum (or the lack thereof) in North American schools. The Association for Computing Machinery (ACM) has published multiple versions of *A Model Curriculum for K-12 Computer Science* (Tucker et al., 2006), and more recently a special branch of the ACM called the Computer Science Teachers Association (CSTA) published the *CSTA K-12 Computer Science Standards* (Seehorn et al., 2011). Both the ACM (www.acm.org) and CSTA (csta.acm.org) have websites with rich repositories of resources for practicing CS high school teachers, as well as opportunities for them to attend conferences about CS education. The CSTA specifically is focused on working to address critical issues in K-12 computer science education by serving as a source of information to K-12 CS teachers, broadening the awareness of the need for CS curriculum standards, and providing professional development to help teachers improve their pedagogical skills (Simard et al., 2010). However, despite these efforts, neither the ACM nor the CSTA curricula are widely used throughout North American schools (Armoni & Gal-Ezer, 2014). One reason these curricula have not gained traction is that schools and districts have to make the effort themselves to try and institute these standards, often without the support of government (Seehorn et al., 2011).

Many schools that do offer CS courses focus more on preparing students to pass the Advanced Placement (AP) CS exams (Armoni & Gal-Ezer, 2014). However, since AP CS is only considered a general elective, and given the excessive academic demands of many high school students, very few of them choose to take the AP CS course because they cannot fit it into their already overloaded academic schedules (Gal-Ezer & Stephenson, 2009; Simard et al., 2010). The CS10K project (https://cs10kcommunity.org/) is an organization that has been working hard to increase the number of students taking AP CS courses. They started off with a goal of having 10 000 well-qualified CS teachers in 10 000 high schools by the end of 2015 (Cuny, 2011). While they are still not close to reaching their goal, they have made significant progress (Brown & Briggs, 2015). CS10K does not explicitly focus on attracting women to CS, however many of their projects are required to address underrepresentation in some way, including gender (J. Cuny, personal communication, January 8, 2016). The National Science Foundation in the United States has created Tapestry Workshops that are geared to help high school AP CS teachers in improving their courses (Cohoon, Cohoon, & Soffa, 2013).

Specifically, they help teachers acquire effective strategies to motivate female students to take, and stick with CS. Evaluations at the University of Virginia showed that teachers who attend these workshops are more likely to actively recruit more female students into CS (Cohoon et al., 2013).

There have also been more localized efforts to improve the number of skilled CS high school teachers. For example, the initiative *"Georgia Computes!"* (Bruckman et al., 2009) was successful in increasing the number of CS high schools with authorized CS teachers by 107%, and was also responsible for providing these teachers with training and direct support in their classrooms. A Town Hall meeting and workshop held at the Grace Hopper Celebration of Women in Computing conference (ghc.anitaborg.org) helped to provide teachers with relevant and practical professional development, and gave opportunities for K-12 teachers to share strategies and best practices for overcoming barriers for female students in CS (Simard et al., 2010). The workshop was particularly successful in inspiring teachers to make changes to their curricula in order to reach out to young women, make assignments relevant to all students, and create opportunities for the success of female students in CS. The University of Washington provides professional development opportunities for CS high school teachers, including strategies for attracting and retaining female students (Eney et al., 2013). While all of these cases were effective at improving the number of effective CS teachers, their impact was relatively small compared to the total number of high schools in North America.

Thus, it can be seen that there are many disparate efforts at improving the CS standards in North American high schools. However, despite these efforts the state of CS in high schools is still one of confusion and inconsistency (Stephenson & Dovi, 2013; Wilson et al., 2010), not an ideal environment for young women to find themselves in.

What Does This Situation Mean for Women in CS?

The lack of a defined CS curriculum and limited support structures for teachers results in either a lack of CS education in schools, or at the very least in poor-quality CS education. This affects all students, including women. Indeed, it seems that women might be more affected than men. For example, female students who were interested in pursuing CS indicated that their high school CS courses did not increase their confidence in CS, nor did they improve their view of women in CS (Pollock, McCoy, Carberry, Hundigopal, & You, 2004). In my correspondence with Lindsay Bradley, the project manager at the CSTA, I was informed that their 2015 survey showed that females only make up 24.7% of high school students taking CS, although this data was for the U.S. only (personal communication, November 17, 2015). Additionally, although the number of people taking AP CS in North America has increased over the last ten years (The College Board, 2014a), the number of female students taking AP CS in 2014 was four times lower than the number of male students (The College Board, 2014c).

There are specific organizations in place to support women in CS, such as ACM's Women in Computing (women.acm.org), the Anita Borg Institute (anitaborg.org), and the Computing Research Association's Committee on the Status of Women in Computing Research (CRA-W) (cra.org/cra-w). However, there is not as much focus placed on CS education in high school as there is for post-secondary education or CS as a profession. For example, the CRA-W's mission statement reads: "Our programs, people, and materials provide mentoring and support for women at every level of the research pipeline: undergraduate students, graduate students, faculty, and industry and government researchers" (cra.org/cra-w/about/mission). While they do mention many levels of the "pipeline", they do not mention any support for high school students. This is a problem, since as we can see the disproportionate levels of men to women in CS starts at a much earlier level than undergraduate. In fact, it has been shown that introducing CS courses in high schools increases the likelihood of female students to pursue CS in higher education (Armoni & Gal-Ezer, 2014).

That is not to say, however, that there has been nothing done to promote CS for women in high schools. In fact, there have been many initiatives to attract young women to study CS in high school (Cohoon, Cohoon, & Soffa, 2013; Eidelman et al., 2011; Eney, Lazowska, Martin, & Reges, 2013; Klawe, 2013; Pivkina, Pontelli, Jensen, & Haebe, 2009; among many others). These initiatives managed to successfully increase the enrolment of female CS undergraduates through enterprises such as community outreach, summer camps, visits to high-tech companies, workshops, peer mentoring, summer research opportunities, and introducing females to CS conferences. I will discuss some of these initiatives in more detail, in order to understand what makes them successful in encouraging young women to enter post-secondary CS studies. However, before we discuss these cases, it is important that we understand the social, psychological, cultural and institutional reasons that influence women's choices to enrol in CS.

Influences on Women's Choice to Enrol in CS

Examining the literature, I found many papers that focus on the reasons behind the lack of female representation in CS. I focused particularly on the reasons that may affect their choice to enrol in CS. It is important here to note again that it is not women's mathematical ability that affects how many are accepted into CS programs. Women have been shown to be just as capable as men in performance in class (Beyer, 2008, 2014), and yet are always less likely to choose to enrol in a CS program, regardless of their ability (Hango, 2013). Why is this so? Through extensive analysis of the research, four distinct categories were found for reasons why women might not choose to enrol in CS: stereotypes and role models of computer scientists, computing confidence and experience, women's values and interest in CS, and CS learning environments.

Stereotypes and Role Models of Computer Scientists

The general stereotypes associated with CS are typically socially unflattering and undesirable – people in CS are thought of as socially awkward, obsessed with technology, deficient in interpersonal skills, lacking outside interests and unskilled at relationships (Cheryan, Drury, & Vichayapai, 2012; Margolis & Fisher, 2002). In other words, they are considered nerds, geeks or hackers (Beyer, 2014). These are traits which are not usually associated with the female gender role (Cheryan, Plaut, Davies, & Steele, 2009; Diekman, Clark, Johnston, Brown, & Steinberg, 2011).

While some of these stereotypes may be representative of a majority of computer scientists, many of them only apply to a small proportion of the group, while others are mostly inaccurate (Cheryan, Plaut, Handron, & Hudson, 2013). However, these stereotypical notions about CS-related courses and careers persist in North American culture, and they influence the behaviour of prospective female students, impacting their decision whether to pursue a degree in CS or not (Beyer, 2014; Chao, 2013; Doubé & Lang, 2012).

The influence of these stereotypes on young women can be seen to manifest in different ways. For example, as early as high school, these stereotypes can diminish women's interest in pursuing CS degrees due to a perception that CS is better suited for men (Bock, Taylor, Phillips, & Sun, 2013). Furthermore, negative stereotype threat (stereotypes of women being inferior in CS tasks) can also influence women's attributions of failure in computer tasks, as well as their performance in those tasks (Beyer, 2014). For example, in a study where women were asked to work on a computer task and were told that men usually perform better than women do, they were more likely to attribute failure to their own inability, while in a reverse situation men were more likely to blame faulty equipment (Koch, Müller, & Sieverding, 2008).

One suggestion put forward to combat the effect of these stereotypes is to promote female role models to act as a positive influence for attracting young women to CS. It is not surprising that women who choose CS as a career are often influenced by the opinions of those close to them, be they family, friends or professors (C. Lang, 2010; Mishra et al., 2014; Roach, McGaughey, & Downey, 2011; Zhang, 2007). This idea is supported by studies that show that female students are more likely to major in CS if they had female computer teachers in high school (Beyer & Haller, 2006). However, conflicting studies have discovered that when young women were exposed to female CS role models who exhibited stereotypical CS attributes, this had enduring negative effects on their interest in CS (Cheryan et al., 2012; Cheryan, Siy, Vichayapai, Drury, & Kim, 2011). These studies also demonstrated that women were positively affected through interaction with non-stereotypical CS role models, regardless of their gender. This suggests that the gender of the role model may not be as important as the perceived similarity or dissimilarity between the student and the role model. It is important to note that in these cases that the opposite was not true for men – in other words, introducing non-stereotypical CS role models does not deter men from pursuing a CS degree (Cheryan, Siy, et al., 2011).

Thus it seems that all the issues discussed above stem from women's reduced sense of belonging in CS, brought about by their perceived dissimilarity from stereotypical CS role models (Cheryan et al., 2012; Cheryan, Siy, et al., 2011). Asgari, Dasgupta, & Stout (2012) have shown that female students exposed to role models similar to themselves changed their implicit self-views, which enabled them to envision themselves in these roles. Therefore, in order to diversify the field of CS, we need to change female students' social perceptions of how they relate to those in the CS field (Cheryan & Plaut, 2010).

Computing Confidence and Experience

A person's confidence in their abilities (often referred to as self-efficacy) has a great effect on their educational and occupational choices (Eccles, Barber, & Jozefowicz, 1999). Specifically, confidence in computing is a predictor of a person's intent to take CS courses (Sáinz & Eccles, 2012). It is therefore worrying that many studies have shown that women tend to have a much lower confidence when it comes to the field of CS (Beyer, 2014; Franklin, 2013; Singh, Allen, Scheckler, & Darlington, 2007; Varma, 2010).

Women are inclined to have lower confidence and less belief in their natural ability in male-dominated domains such as CS (Beyer, 2014; Seymour & Hewitt, 1997). This confidence is inaccurate when compared to women's actual skills and performance (Beyer & Haller, 2006; Beyer, 2008). Men tend to have greater confidence and less anxiety in using computers and programming than women (Stoilescu & Egodawatte, 2010; Varma, 2010). This may lead one to think that only confident women choose CS, but it seems that even women who choose CS are less confident than men in the same field (Franklin, 2013). In fact, Beyer & Haller (2006) found that men in majors unrelated to CS actually had more confidence in their computing skills than women in CS majors. This may be due to women submitting to stereotypic views of women's computing ability, but studies suggest that this is the case even for women who believe that females have as much computing ability as males (Beyer, 2014).

Low self-efficacy impacts how women interact and are perceived in class. For example, students who are less confident are likely to be more risk-averse, choose easier projects when given the option, and ask questions to get confirmation (even though they already know the answer) (Franklin, 2013; Redmond et al., 2013). This may lead professors and peers to believe these students are less knowledgeable than they really are (Franklin, 2013), further undermining their confidence. If this lack of confidence is unaddressed, it may lead to a downward spiral of falling grades, reduced class attendance and despair, eventually resulting in women quitting the subject (Seymour & Hewitt, 1997).

This lack of computing confidence in women is not a new discovery. A comprehensive literature review performed almost 10 years ago discovered an overwhelming gap in women's computing confidence and self-assessment of ability compared to men, even when controlling for academic ability and performance (Singh et al., 2007). They also found that it was this gendered self-representation and lack of confidence that affected women's intention to pursue and persist in CS. But what causes this lack of confidence in women? Many indications point to women's lack of previous computing experience as the determining factor.

Women's confidence in their computing ability is highly affected by their previous computer experience (Beyer, 2014; He & Freeman, 2010). Women are less likely to have programming experience before entering university (Beyer & Haller, 2006; He & Freeman, 2010; Margolis & Fisher, 2002). They are also usually exposed to computers at an older age (Looker & Thiessen, 2003; Stoilescu & Egodawatte, 2010; Varma, 2009), which means that their interest in CS appears much later than that for men (C. Lang, 2010).

Exposure to computers and CS before college can take on two forms – formal exposure through high school CS classes, and informal exposure through peers and family. It seems that in both cases, women are less likely to be exposed to CS than men. For example, Varma (2009) discovered that female high school students had late exposure to computers both at home and in schools, and that high school teachers rarely motivated female students towards CS. Indeed, men are much more likely to have taken a CS class before entering college or university (Beyer, 2014), and as discussed previously the current proportion of female high school students taking CS classes is much lower than that for men (The College Board, 2014c). Young women are also less likely to have access to computers in their homes, and they tend to spend less time on the computer than men (Looker & Thiessen, 2003; Stoilescu & McDougall, 2011).

These experiences are crucial in shaping young women's goals and ambitions for their future careers. Women who have computing experiences in high school are more likely to show interest in pursuing CS courses in college (He & Freeman, 2010), particularly if those experience were positive and they received encouragement from their teachers (Beyer, 2014; Zarret et al., 2006). Conversely, one bad classroom experience can turn female students off studying CS

(Cohoon et al., 2013; Eney et al., 2013), and thus women's first experiences in CS courses are crucial for initiating and sustaining their interest in CS (Alvarado & Dodds, 2010; Roach et al., 2011). Informal education outside of school also plays an important role in shaping students' experiences, confidence, and anxiety; particularly for female students who are less likely to have these opportunities (Stoilescu & McDougall, 2011). Mentorship and parental support have a strong role to play in encouraging women to pursue CS careers (Redmond et al., 2013).

In conclusion, women tend to have less computing experience than men, and are more likely to see this lack of experience as a deterrent to enrolling in post-secondary CS courses (Carter, 2006; Margolis & Fisher, 2002). A key contributing factor which determines whether women will experience computers before entering college is their interest in computers, and the values associated with women and computing (Beyer, 2014).

Women's Values and Interest in Computer Science

There have been many studies that show that women have different values to men when it comes to choosing their careers (Eccles et al., 1999; Rommes, Overbeek, Scholte, Engels, & De Kemp, 2007; Su, Rounds, & Armstrong, 2009; Weisgram, Dinella, & Fulcher, 2011). The academic pathway that women end up selecting has a great deal to do with their values, and how these values are reflected in the career they are considering (Eccles et al., 1999). Young women "systematically compare what they are good at, what they want from a job, and what activities they like, with their (in)correct expectations of a particular profession" (Rommes et al., 2007, p.299). Thus women's values will dictate their interest in considering CS as a career.

Compared to men, women tend to place more value on fields of study that are perceived as people- or society-oriented, less competitive, in which they can help others and have opportunities to combine career and family (Beyer & Haller, 2006; Beyer, 2014; Eccles et al., 1999; Margolis & Fisher, 2002). Women are also much more inclined than men to have a greater interest in people as opposed to objects (Su et al., 2009). As discussed previously, the CS field suffers from a variety of (incorrect) stereotypes, many of which imply that it is a field that is object-oriented, competitive, has no direct positive impact on society, and does not promote social interaction in the workplace (Cheryan et al., 2013). Women have indicated that they place less value on fields involving math and computer work (Eccles et al., 1999; Su et al., 2009), and that they would rather work with people than computers (Rommes et al., 2007). This often leads to CS being a field that does not represent women's values, and is therefore a career they have less interest in pursuing.

Interest has shown to be vital to women's academic performance, as it provides them with direction, vigour and persistence (Nye, Su, Rounds, & Drasgow, 2012). College students who showed more interest in CS were more likely to major in CS (Denner, Werner, O'Connor, & Glassman, 2014). However, female CS majors often show less interest in CS than male CS majors (Beyer & Haller, 2006). When they do show interest, women are more interested in CS as an academic tool that can be used to impact society, rather than in the programming aspects of the field (Beyer & Haller, 2006; Carter, 2006; Stoilescu & Egodawatte, 2010). In cases where women viewed CS more positively than men, they were still less interested in taking CS courses because they did not fit into "their interests and value system" (Beyer, 2014, p.172). Even women with high self-efficacy in CS are influenced by this effect (Beyer, 2014; Eccles et al., 1999), which suggests that gifted young women who could contribute greatly to the field are being driven away because their values conflict with the perceived values implicit in CS.

Thus, if women do not believe that a CS career reflects their personal values, they will have no interest in pursuing an education in CS. There are many careers within CS that are people-oriented and have positive impacts on society (Cheryan et al., 2009, 2013), however this knowledge does not seem to have permeated into people's general consciousness. This suggests that in order to attract greater numbers of women into CS, we need to present CS courses as creative, applied, people-oriented, and relevant to society (Beyer, 2014; Doubé & Lang, 2012).

Computer Science Learning Environments

For decades, masculine culture has dominated both academic and work environments in CS (Margolis & Fisher, 2002; Singh et al., 2007). This masculine culture favours objectivism, rationalism, emotional detachment, and abstract theoretical approaches to problem solving; whereas a feminine approach involves engaging with the social world and a holistic approach to problem solving (Singh et al., 2007). While these may be generalizations, the fact stands that women entering CS programs are discouraged from persisting in these programs due to the male-dominated environment they find themselves in (Beyer, 2014; Margolis & Fisher, 2002; Singh et al., 2007). This environment is typically one with a high ratio of men to women, exhibiting many persistent non-feminine stereotypes. These environments could produce in women a reduced sense of belonging which, as previously mentioned, is a large contributor to women's decision to give up on CS education (Cheryan et al., 2012).

One would therefore think that increasing the ratio of women to men in CS classrooms would help diminish the effect these environments have on women. However, it seems that the actual design of these learning environments may need to be changed as well (Beyer, 2014; Margolis & Fisher, 2002). It has been demonstrated that stereotypical CS environments can have a negative influence on female interest in CS (Cheryan, Meltzoff, & Kim, 2011; Cheryan et al., 2009). By simply replacing the objects in a CS classroom from ones that are considered stereotypical in CS to ones that are not, Cheryan et al. (2009) were able to increase women's interest in CS. They found that even objects can broadcast CS stereotypes, which in turn can deter women who do not identify with these stereotypes from joining CS. In a similar experiment, changing the design of a CS virtual classroom from one that was stereotypical to one that was non-stereotypical significantly increased women's enrolment intentions, anticipated success, and sense of belonging in their CS course (Cheryan, Meltzoff, et al., 2011). These effects occurred "even when the learning material, gender of the professor and gender ratio of the classmates were identical, isolating the physical environment as a key determinant of women's choices and expectations" (p. 1825). Interestingly, in both cases this had no adverse effect on men, perhaps because the non-stereotypical objects were not feminine in nature.

Some educational institutions, such as Carnegie Mellon University, have shown that it is possible to have a balanced computing environment, in which the differences between men and women tend to dissolve (Blum & Frieze, 2005; Frieze & Quesenberry, 2013). It seems that under certain conditions women and men can be peers that "fit successfully into a CS environment and help shape that environment and computing culture, for the benefit of everyone, without accommodating presumed gender differences or any compromises to academic integrity" (Frieze & Quesenberry, 2013, p.445).

Research suggests that CS teachers and professors need to be careful and consider the implicit messages they send to students when they are designing their CS learning environments, be they physical or virtual (Beyer, 2014; Cheryan, Meltzoff, et al., 2011; Cheryan et al., 2009). Certain masculine or stereotypical environments may project identity-based messages about who does not belong and discourage women from entering the field, or believing they can achieve success in CS (Cheryan, Meltzoff, et al., 2011). Changing the design of these environments may be a way to increase women's interest in enrolling and succeeding in CS. The idea is not to make CS learning environments more feminine, but to create a culture which is inclusive of all, in which students can find a sense of belonging no matter their gender.

Examples of Solutions for Attracting Women to Computer Science

This section includes the best examples of studies which have shown methods of attracting young women to CS, based on the literature review. Since my focus is on recruitment of women into university CS courses, I will mainly be focusing on studies that involved female high school students. However, of the many initiatives I discovered, surprisingly few of them were created to increase interest in CS amongst female high school students. In fact, the number of studies based on high school programs pales in comparison to the number of studies aimed at students already in university or college. That being said, some universities and colleges actually allow students to declare their major after their first year of studies. This means that recruitment into undergraduate CS occurs not just in high school, but also in the first year of university

(Cohoon et al., 2013). Thus I will also investigate some examples of how female first-year college students were successfully attracted to enrolling in CS.

Initiatives for recruiting high school students include summer programs and academies instigated and run by universities, and curricular efforts applied directly in high schools. Strategies for recruiting university students involved changing introductory CS classes, providing CS mentors for female students, and providing scholarships, awards and opportunities to attend CS conferences for women. I will first give examples of these initiatives and strategies and then discuss why and how they were successful at recruiting young women into CS.

Universities Hosting Academies.

Many universities host academies in an attempt to recruit high school students into their CS programs. These universities were most commonly located within the same region as the high schools that they outreach to. Even though many examples were found for university CS outreach programs, there were only a few that focused exclusively on attracting women (Doerschuk, Liu, & Mann, 2011).

Girl's POWER (Programming Of the Web Rocks!) is an 8 week CS summer camp for female high school students at the University of Delaware (Pollock et al., 2004). The camp was run by senior female CS professors with help from graduate and undergraduate assistants. Surveys taken at the end of the program indicate that the summer camp had a positive impact on female high school students' perceptions, self-confidence, and interest in pursuing CS careers. Even the students with no prior experience acquired confidence in their CS ability in this environment.

Another summer outreach program was run by Pennsylvania State University's Women in Science and Engineering (Rosson et al., 2009). These were a series of programming workshops designed by college women and targeted towards female high school students. The activities were part of *wConnect*, a project for building an online community of women in CS. The workshops improved the female students' confidence in CS knowledge, enthusiasm towards CS topics, and encouraged them to participate in future CS-related activities.

An ongoing high school outreach program in CS is the *Young Women in Computing* (YWiC) program run by New Mexico State University (Pivkina et al., 2009). This program involves CS summer camps for female high school students as well as other motivational activities throughout the academic year. Based on a three-year study, the researchers have observed a significant improvement in female students' confidence, attitude, and CS knowledge as a result of participation in YWiC. They also observed that over the years, students entering the program had a better preparation in basic CS. This was a result of the concerted effort by local schools, which were inspired by the program to enhance the presence of CS in their curricula.

As part of its mission to increase the participation of women in computing, the Lamar University in Texas has instituted the *Increasing Student Participation in Research Development* (INSPIRED) program, which conducts computing academies for female high school students (Doerschuk et al., 2011). The academies are organized and run by female undergraduates in the university, and are designed to increase students' knowledge of and interest in computing. Through participation in the academies, many young women have gained significant knowledge and interest in CS.

The *“Georgia Computes!”* alliance (gacomputes.cc.gatech.edu) is attempting to change the entire state of Georgia’s CS education pipeline (Bruckman et al., 2009). The Georgia Institute of Technology, the Georgia Department of Education, the University System of Georgia, the YWCA, and the Girl Scouts of Greater Atlanta, Incorporated have teamed up to increase young women’s interest in pursuing CS as a career. Parts of this program involve high school CS summer camps, after-school Teen Girls in Technology programs run by undergraduate and graduate students, and Girl Scout weekend CS workshops. These programs have been successful in improving female students’ attitudes towards computing and increasing their interest in pursuing CS after the program has ended.

The *"Girls on the Go: The Mobile Computing College Experience"* was a summer camp hosted by Miami University which encouraged female high school students to pursue computing-related degrees in college (Gannod, Burge, McIe, Doyle, & Davis, 2014). The camp was successful in raising awareness amongst the students of the role of computer scientists and the relevancy of computing for solving real world problems.

The University of Washington has hosted summer CS day camps for all high school students, but specifically targeting young women (Eney et al., 2013). They had female majority in all their sessions, and had year-round follow-up activities to keep the students engaged in computing.

High School Initiatives

There have been a few initiatives in high school to promote CS to women that were not based in university programs. For example, The Girls’ Middle School in California has made CS at the core of their curriculum, with every student taking at least three years of CS courses (Wilson et al., 2010). They focus on overcoming stereotypical CS perceptions and solving real-world problems using CS concepts. They introduce their students to the whole breadth of the CS field, and make it clear that anyone has the ability to learn CS. Another example is the *Scalable Game Design Project* (Webb, Repenning, & Koh, 2012), which used game design and programming to engage female students in CS. They also promoted curriculum change in multiple high schools that transformed traditional CS instruction to one of guided discovery, in which learning happens just-in-time and different scaffolding approaches are used to support students in their learning. Student ownership of design was encouraged, and they found that female students were motivated by this change in instruction.

Girls Who Code (girlswhocode.com) is a U.S. non-profit organization which is working towards increasing the number of women in CS by running summer programs which teach computing skills like programming, robotics and web design skills to young women in high school. These 7-week sessions also include visits to tech companies such as Facebook and Twitter. Since beginning in 2012, *Girls Who Code* has served 3331 young women in 24 states (Saujani, 2015). 88% of their alumni are majoring or plan to major in CS, and these women all named *Girls Who Code* as a major factor in their decision to do so (Saujani, 2015). Many of these women had a different or undecided educational path before they encountered *Girls Who Code*, but this program was successful in engaging their interest in CS. A similar program exists in Canada called *Ladies Learning Code* (ladieslearningcode.com). One of their initiatives is called *Girls Learning Code* and provides workshops, camps and school programs for young women in Canadian high schools, with over 3400 participants in over 20 cities since 2012

(Truong & O'Brien, 2016). They also organize an annual *National Girls Learning Code Day* (ladieslearningcode.com/girlscodeday). During their 2015 initiative, they hosted 28 workshops in 24 cities across Canada and had over 1000 girls (8-13 years old) learning to make websites. 88% of girls responded "yes" to "I can be an expert in technology", and almost all of the learners were interested in attending another workshop (Sariffodeen, 2015).

Changes to Introductory Computer Science Courses

A common strategy employed by many universities who are trying to recruit women into CS is to make changes to their curriculum and their introductory CS courses. Harvey Mudd College, under the guidance of their president Maria Klawe (a former UBC CS professor), revised their introductory CS course to include a track specifically focused to help students with no previous CS background, as well as providing optional lab sessions for students to get help with difficult concepts (Alvarado & Dodds, 2010). The University of Virginia discovered that female students' previous programming experience was impacting their choice to enrol in their CS program (Cohoon et al., 2013). Their current introductory CS program did not have procedures in place to help these students, and so they created a secondary course specifically designed for students with low experience. They also restructured their original course to cluster students with similar backgrounds, in order to prevent women from feeling isolated. California Polytechnic State University created a brand new first year CS course that featured different tracks and reflected student interests (e.g., robotics, art, music, games), as well as providing a "big picture" view of computing (DuBow, Vakalis, Perez-Quinones, & Black, 2013). Virginia Tech offers CS modules in the summer to incoming students to increase their computing experience before coming on campus (DuBow et al., 2013). The University of Washington redesigned their CS courses to have less emphasis on previous knowledge of computing technologies, making it clear that hard work and not innate talent are predictors of success in the course (Eney et al., 2013). In order to have a greater impact on their female students they also provided concrete support structures, offered seminars on women in computing in tandem with the course, emphasized the interdisciplinary nature of CS, explored the applications of CS in society, and had a large number of teaching assistants, of which 40% were women. Stanford University changed their curriculum to provide a broader context for impactful work in CS, and more options for female students interested in different aspects of CS (Redmond et al., 2013). All of these universities have managed to significantly increase women's participation in their CS programs.

Mentoring University Students

Many universities have seen benefits in providing mentors for incoming female students. Mentoring allows for a space where women experienced in CS share their knowledge and experiences with younger women, providing advice, support and motivation to succeed (Cozza, 2011). Universities provide mentoring opportunities in many ways. For example, by pairing new female students with women in upper-division CS programs, having a female CS department head, or by providing mentoring services for students in need (DuBow et al., 2013). Universities sometimes work with external organizations dedicated to increasing gender diversity such as Computing Research Association's Committee on the Status of Women in Computing Research (CRA-W) to provide mentoring activities to female students with women in the CS industry

(Cohoon et al., 2013). Mentoring sometimes works the other way as well. As mentioned previously, some programs offer opportunities to undergraduates to mentor high school students in academic workshops and summer programs. This not only helps the female high school students, but also the university students involved in providing the mentoring (Bruckman et al., 2009; DuBow et al., 2013).

Conferences, Scholarships and Awards

Another common remedy used by universities to recruit women into CS is by providing scholarships to women interested in CS and awards to those who have already shown aptitude in the field. For example, the NCWIT Award for Aspirations in Computing honours both high school teachers and students for their computing-related achievements and interests (Eney et al., 2013). The African-American Women in Computer Science (AAWCS) scholarship program provides financial support to specifically help women who might otherwise struggle to afford CS education (DuBow et al., 2013). The Google Anita Borg Memorial Scholarship (http://www.google.com/anitaborg/) provides financial support for women intending to pursue computing-related degrees. Even UBC has specific scholarships for female students, such as the SIMBA Technologies Award in Computer Science (UBC Department of Computer Science, 2016a). However, many of these awards already assume that the women have some interest in CS. In order to foster this interest, many universities send their first-year female college students to conferences specifically targeted at engaging women in CS.

There are a number of conferences in North America that celebrate women in computing, such as The Richard Tapia Celebration of Diversity in Computing (tapiaconference.org) and The

Canadian Celebration of Women in Computing (www.can-cwic.ca). However, the most well-known and important conference is the Grace Hopper Celebration of Women in Computing (GHC) (ghc.anitaborg.org). The GHC is a series of conferences designed to bring the research and career interests of women in computing to the forefront, representing perspectives from industrial, academic and government communities. It is the world's largest gathering of women technologists. While it is not specifically geared towards undecided undergraduate students, several colleges and universities have successfully recruited women into CS by sending their first year female college students to GHC (Alvarado & Dodds, 2010; Alvarado & Judson, 2014; DuBow et al., 2013; Eney et al., 2013). Specifically, attending GHC inspired female students with little or no CS background to take CS classes and choose CS as their major (Alvarado & Judson, 2014). The experience also boosts women's confidence, provides them with role models, and informs them about the CS field (Eney et al., 2013). While GHC has the most profound effect on female students already considering CS as a possible major, it has also helped recruit women who were not interested in CS at all before attending the conference (Alvarado & Judson, 2014).

What do These Have in Common?

Looking at the strategies and solutions employed by the universities and individual schools, a pattern emerges in what these programs are doing to attract young women to CS. This pattern is unsurprising, as it relates directly back to the four influences which affect women's enrolment discussed previously: stereotypes and role models of computer scientists; computing confidence and experience; women's values and interest in CS; and CS learning environments.

Stereotypes and role models. Almost all of the university programs mentioned above used female staff or college students exclusively to organize their high school academies, as well as to provide mentors and teachers to the students (Bruckman et al., 2009; Doerschuk et al., 2011; Pivkina et al., 2009; Pollock et al., 2004; Rosson et al., 2009). In fact, some programs even had female role models come in from all levels of the education pipeline (Pivkina et al., 2009; Pollock et al., 2004), while others focused on eliminating the classic stereotypes associated with a CS career (Wilson et al., 2010). First-year female college students were also provided role models, either by having a female CS department head (DuBow et al., 2013), female teaching assistants (Eney et al., 2013), providing female CS mentors (Cohoon et al., 2013), or providing them opportunities to see female experts in the CS field at the GHC conference (Eney et al., 2013). By providing role models that the students could identify with, these programs were able to reduce the stereotype that CS is chiefly for men, while having a positive impact on female students' perceptions of women in CS.

Computing confidence and experience. The programs that were directed towards young women in high school were able to give these women computing experience at a younger age, which will improve their confidence once they reach college. In fact, the *"Georgia Computes!"* program also impacted some elementary schools (Bruckman et al., 2009). Some university programs also took steps to ensure that women with little prior computing experience were not intimidated by their CS courses, either by providing specific courses for students with lower experience (Alvarado & Dodds, 2010; Cohoon et al., 2013), or by providing modules to increase students' experience before entering their CS courses (DuBow et al., 2013). Some programs used scaffolding approaches to help less-experienced students succeed (Rosson et al., 2009; Webb et al., 2012). For example, open-ended projects were used to handle a variation in prior knowledge and helped the students feel confident in their ability to grasp CS concepts (Pollock et al., 2004). Peer-teaching from more experienced students was also a factor that improved female students' confidence in their computing abilities (Pollock et al., 2004). Some programs had a goal to not only affect students, but also raise parent and administrator appreciation for computing (Cohoon et al., 2013). By having parents and schools support female students in CS classes, they could raise these students' confidence in their CS abilities, and make them feel as if they belong in this field.

Women's value and interest in CS. It seems that one of the more important factors for influencing female students' perceptions of CS was in showing them the relevancy of CS for solving real-world problems (Gannod et al., 2014; Redmond et al., 2013; Wilson et al., 2010). Many of the programs focused on educating young women on the different kinds of careers that studying CS can open up for them (Bruckman et al., 2009; Gannod et al., 2014; Pivkina et al., 2009; Pollock et al., 2004). Some programs did this by applying computational thinking to other domains such as Biology or Music (DuBow et al., 2013; Pivkina et al., 2009), while others emphasized the interdisciplinary nature of CS and its applications to society (Eney et al., 2013; Redmond et al., 2013). By putting computing in different contexts, female students were able to find an aspect of CS that matched their values, and therefore sparked their interest in this field (Bruckman et al., 2009). Students also mentioned that they appreciated understanding that the tools they acquired in CS would be useful for their future studies (Pivkina et al., 2009).

CS learning environment. Almost all of the summer programs mentioned above were exclusively geared towards female high school students. This created CS learning environments that were very different to the usually male-dominated CS classrooms. Not only were the classes female-only, but they were also designed and run by women, which means that the physical environment was more female-friendly than a typical CS environment (Pivkina et al., 2009; Rosson et al., 2009). Another noteworthy similarity was the small ratio of students to instructors (Doerschuk et al., 2011; Gannod et al., 2014; Pollock et al., 2004), which meant that students received more personal attention than in a typical classroom. While the university CS courses were not all-female, the structure of the courses was changed to make them more female-friendly and to prevent women from feeling isolated (Cohoon et al., 2013; Eney et al., 2013). Thus in most cases female students were learning CS in an environment that did not make them feel excluded or unwelcome. One way for women to feel included is by having shared interests with other students, and it seems that one of the most common interests for CS students is gaming.

Gaming and CS

It is necessary here to mention the link between CS and gaming. One of the commonly cited pathways for attracting women to CS is video gaming (Denner et al., 2014; Margolis & Fisher, 2002). People who are avid video game players are attracted to the programming aspects of video gaming (Kafai, Heeter, Denner, & Sun, 2008), which may lead to further interest in CS-related careers. Gaming is a strong predictor of women's intention to enrol in CS (Denner et al., 2014), however studies suggest that men are more likely than women to mention gaming as a motivation to pursue a CS major (Carter, 2006; Denner et al., 2014; Margolis & Fisher, 2002). A decade ago this could have been explained by the fact that men played games more frequently than women (Ogan, Robinson, Ahuja, & Herring, 2006). However these days women make up around 44% of the total people who play video games (Entertainment Software Association, 2015), although it does seem that women tend to spend less time playing video games than men (Denner et al., 2014).

Many current students have grown up playing video games (Edery & Mollick, 2009). The use of video games in education has increased significantly over the past few decades and shows promise of engaging these students (Edery & Mollick, 2009; Schifter & Cipollone, 2013; Van Eck, 2006; Warren, 2015). However, the use of games to motivate school students in computing has shown mixed results for women (Bayliss, 2009). While some studies have demonstrated that it is possible to use games or game design to encourage young women to pursue CS (Leutenegger & Edgington, 2007; Webb et al., 2012), others have shown the opposite (Robertson, 2013). In the latter case, young women did not enjoy the gaming aspects as much as men, and were in fact discouraging from pursuing CS in the future. Bayliss (2009) suggests that the important question is not if games will motivate women to pursue CS, but what *type* of games will motivate them. It is important to be aware of gender differences when deciding on the type of game to be used, with gender-neutral games being the preferred type by many researchers (Bayliss, 2009; Leutenegger & Edgington, 2007; Sung, 2009; Zeffertt, Thinyane, & Halse, 2014). An inclusive game that appeals to both genders and does not assume an already high level of expertise has much better chances of succeeding in generating enthusiasm for CS in women, instead of intimidating them (Sung, 2009; Zeffertt et al., 2014). When using game design in CS classes it is important that women are able to bring their own personality into the design, which in turn will give them ownership and motivate them to continue with CS (Webb et al., 2012).

The game content is also important, as more violent games tend to disengage female students (Leutenegger & Edgington, 2007; Sung, 2009), while creative games that involve storytelling have been used to encourage young women to become interested in programming (Denner, Werner, & Ortiz, 2012; Kelleher, Pausch, & Kiesler, 2007).

In conclusion, it is evident that gaming is an important source of motivation for young women to be introduced to programming, and can be a conduit to bring more women into CS. It is important to note here that although gaming may serve as motivation to take CS courses, it does not necessarily predict performance in those classes (Beyer & Haller, 2006).

Women and CS in Other Countries

The issue of low female enrolment in CS is not one limited to North America, but can be seen worldwide, particularly in western industrial countries (Charles & Bradley, 2006). However, there are certain countries which do not seem to have this problem, or at least not to the same extent as North America. In this section I will compare studies performed in other countries with the issues discussed above in order to emphasise similarities and differences. This will highlight which specific issues might help lead to increasing the enrolment of women in North America.

Similarities

Many countries have had similar problems to those found in North America. For example, Dutch researchers discovered that young women do not choose CS as a career because of the stereotypes associated with being a ‘computer person’ (antisocial unattractive male) (Rommes et al., 2007). In Australia, CS is not seen as a career in itself, and women are socialised away from the discipline (C. Lang, 2010). CS is not seen as valuable to society, and young Australian women are less likely to get any computing experience at home or in school (Downes & Looker, 2011). In Germany, a study discovered that stereotype threat can influence women's attributions of failure in a computer task, demonstrating women's low confidence in their own computing abilities (Koch et al., 2008). A study in Greece showed that women in CS are drawn to different aspects than men – they are more likely to choose courses that can be used socially or to help people (Kordaki & Berdousis, 2014). The gender gap in CS education in Uganda was found to be due to factors such as discouragement from society, lack of mentors and role models, lack of scholarships for women, and low computing confidence and experience of female students (Ochwa-Echel, 2011). Some programs in Israel have successfully managed to encourage female high school students to enrol in college CS courses by exposing them to female role models in CS careers (Eidelman et al., 2011) and providing them with CS courses in high school (Armoni & Gal-Ezer, 2014). From these cases we can see that many countries have very similar problems to North America when it comes to recruiting young women into CS. However, there are other countries in which the relationship between women and CS is very different.

Differences

In Malaysia, CS is not perceived as a masculine pursuit. In fact, there are large numbers of women in CS, and CS is seen socially as providing suitable jobs and good careers for women (Othman & Latih, 2006). The "office space" environment is seen as being a safe and protected environment for women to work in (Lagesen, 2008). Interestingly, women in this environment were not just interested in the social aspects of the field, but were also interested in more “masculine” areas like software engineering and programming. This may be due to the lack of the “hacker” or “geek” stereotype usually associated with computer scientists, and the belief that hard work, and not intrinsic skill, is the main way to succeed in CS (Lagesen, 2008). Women in Malaysia also have many female role models to aspire to, and the large number of women in CS programs make the culture more welcoming to newcomers (Othman & Latih, 2006). In India, there are high numbers of females entering CS in college, even though they don’t get exposure to it in high school (Varma, 2011). The reason for this was found to be women’s high confidence in their mathematical abilities, which translated to high confidence in CS. In Armenia, researchers found that women were more numerous in CS because they did not seem to be affected by the same issues as North American women (Gharibyan & Gunsaulus, 2006). For example, CS is considered a mathematical field that is suitable for women, male dominated fields are not intimidating to women, absence of female role models does not seem to affect women, and even though the opinion that women are not as good as men exists in many fields (including CS) this opinion does not seem to have much effect on women.

What do These Similarities and Differences Indicate?

From just these few studies we can see that there are definitely cultural aspects that affect women’s attitudes towards and interest in CS. However, what is important here is that those cultural differences can in fact be used to highlight the problems facing CS education in North America. Once again, we can see the importance of the four influences discussed earlier: stereotypes and role models of computer scientists; computing confidence and experience; women’s values and interest in CS; and CS learning environments. For example, we saw that countries that lack the classic CS stereotypes were more likely to recruit more women into CS (Lagesen, 2008). Also, countries which had role models for women (or in which women did not seem to need role models) also had a much higher proportion of women to men in CS (Gharibyan & Gunsaulus, 2006; Othman & Latih, 2006). Countries in which women were more confident in their mathematical abilities (and thus their programming abilities) were also more likely to recruit those women into CS (Varma, 2011). In countries which deemed CS as appropriate for women, CS careers lined up with women's values, thus creating interest in women to pursue it as a career (Lagesen, 2008; Varma, 2011). Finally, countries which had CS cultures that were more welcoming to women, or in which women did not feel intimidated by male-dominant culture, were more likely to have a higher proportion of women in CS (Gharibyan & Gunsaulus, 2006; Lagesen, 2008). While it is not feasible to change the culture of North America, I believe that these issues highlight the problems that we need to deal with in CS education.

Proposed Solutions

Now that we have a good idea of the problems facing women in CS, we can start looking at some of the solutions that could be used to help. Most of the research papers analysed in this review offered one or more solutions to solve the problem of low female enrolment in CS (Beyer, 2014; Blum & Frieze, 2005; Bruckman et al., 2009; Carter, 2006; Frieze & Quesenberry, 2013; Gal-Ezer & Stephenson, 2009; Simard et al., 2010; Stephenson & Dovi, 2013; Varma, 2010; Wilson et al., 2010, among many others). Many of these solutions were similar in nature, and thus I have compiled a table discussing the solutions proposed (Table 1).

Table 1

Proposed solutions to issues regarding low female enrolment in university CS courses

Problem addressed	Proposed Solutions	Explanation
CS is not seen as a viable career for women	Dispel stereotypes regarding CS	In order to engage more women in CS we need to dispel the myths and misconceptions about CS as a discipline, as well as the stereotype associated with being a person in CS. To do this we need to educate female students about the wide degree of opportunities that studying CS can open up for them, and give them examples of people within CS that do not conform to typical CS stereotypes.
	Provide CS role models for female students	We need to provide role models in CS education and within the CS industry that do not exhibit typical CS stereotypes that are incompatible with the female gender role.
	Make clear the societal importance of CS	We need to make it clear that CS has a wide range of applications, has an impact on society, and is useful for a variety of disciplines that connect to women's values.
	Educate parents, peers and teachers on CS for women	It is necessary to provide relevant career information for students, parents, and guidance counsellors. By teaching parents, peers and teachers about the possibilities and applications of CS for young women we can get them to encourage these women to enter the field.
Lack of direct recruitment of women into CS	Create mandatory CS classes in high school and promote CS courses in university first-year programs	Making CS a mandatory subject in high school will ensure that women will be equally exposed to it as men, thereby increasing the opportunities for female high school students to gain computing experience and confidence in their computing abilities prior to entering college. The same applies to first-year college programs.
	Increase outreach from universities and colleges to high schools	Increasing the number of effective university CS outreach programs will help increase the number of young women exposed to and engaged in CS. These local efforts are important as they are each specific to the area in which they are in.
	Produce more educational campaigns that promote CS education for women	We need to increase the awareness of CS as a field for women through far-reaching campaigns geared specifically towards younger women. Increasing the number of women in CS will make it more appealing to future women considering applying, and will change the nature of the CS learning environment that women find themselves in.
	Improve young women's access to CS conferences, funding, and scholarships	Creating funding opportunities for women will make CS an appealing field and will help those women who are interested but cannot afford to study. Attending conferences will expose women to the depth and breadth of the CS field.

Poor CS education standards in North American high schools	Clearly define CS education and standards	Create a well-defined set of K–12 computer science standards that can be applied nationally, with a clear idea of what constitutes CS education. These standards should include issues on gender inclusion and equality.
	Improve the certification process for CS teachers and educate them on issues of gender inclusion	We need to increase the number of well-trained CS teachers to reach all schools. Improving the quality and number of teachers will make it more likely that young women will be attracted to these CS courses. We need to educate these teachers on how to make their CS classes more attractive and appealing to female students. The teachers must learn about different learning styles, social contexts, classroom environment design and teaching techniques in order to encourage women into CS.
	Create professional development opportunities for CS teachers	Many current CS teachers lack the necessary preservice training to teach CS effectively, particularly when it comes to teaching CS to women. We need to provide opportunities for these teachers to learn teaching styles and strategies to recruit young women into CS.
	Change CS courses in high schools and university to better reflect women's values	CS courses should explore all aspects of the discipline and expose students to a multitude of applications of the field. The classes should foster diversity and should be engaging for all students, not just the technologically adept. These courses need to be relevant, exciting, to stress creativity and should inspire female students to see computing as an enabling force in whatever areas of interest that they have.
	Count computer science courses toward a student's core graduation requirements	By allowing CS to count as a credit towards entering university, this will give many students the option to choose CS without it being an "extra course" that overwhelms their already packed course load. It will make CS a viable option for many high school students, including women.
	Offer interdisciplinary CS programs in high school and first year university	These CS programs should make it clear that CS can be used in different fields, and is often necessary for completing degrees in these fields. The programs should be designed not just for students with interests in CS, but also those with more general interests in science, engineering, and the humanities.
	Reach policy makers, government and industry and get them to understand and support the issue at stake	Make it clear to the people that can affect policy change in districts, states and provinces that underrepresentation of women in CS is a critical issue. Create and disseminate materials on careers in CS specially targeted for female populations, drawing from experiences of women in the industry. Help policy makers understand that access to CS education is a social justice issue.

Many of these proposed changes speak directly to the four influences which affect women's enrolment discussed previously: stereotypes and role models of computer scientists; computing confidence and experience; women's values and interest in CS; and CS learning environments. Other solutions speak to the training of teachers and changing of the CS education system, addressing the issues above which discussed the state of CS in high schools.

The most important trend observed in any of these proposed solutions was that more and more papers are calling for systemic change (Bruckman et al., 2009; Gal-Ezer & Stephenson, 2009; Simard et al., 2010; Stephenson & Dovi, 2013; Wilson et al., 2010). In other words, any changes to CS education need to be implemented at all levels that impact K-12 CS education: federal and state governments, state/provincial boards of education, district-level administrators, school principals, and classroom teachers. However, this call for systemic change has been going on for decades (Blum & Frieze, 2005; Carter, 2006; Margolis & Fisher, 2002), and yet sadly "years of attention and funding applied to women in computing issues have not paid off" (Frieze & Quesenberry, 2013, p. 5). Many other countries such as Norway, Germany and Israel have managed to use similar strategies to those in Table 1 to bring about nationwide reform in high school CS education, and have been successful at recruiting women into university CS courses (Armoni & Gal-Ezer, 2014; Hubwieser, 2012; Lagesen, 2007), but it seems that North America is still far behind these results (Zweben & Bizot, 2015).

My analysis has revealed that even though momentum has been steadily building to recruit more women in CS, most of this momentum has been from certain universities, or private companies, without the support of government. There are a multitude of smaller programs that are doing a great job in recruiting women into CS, but these programs are disconnected and only affect a small amount of women. There are some larger programs, such as the Computer Science Teachers Association (CSTA) and project CS10K, which as previously mentioned are working hard towards bringing CS standards into high schools and recruiting young women into the field. However, even these large-spanning projects fail to reach all schools in North America, and they are unable to enact changes at the governmental level. That is not to say that these programs have not done any good at all, on the contrary some have been very effective. The next step needs to be to communicate the importance of this issue to policy makers in government that can enact effective changes in the CS education curriculum to attract young women to this discipline.

It seems that some parts of North America have recently stepped up to this challenge. In his 2016 State of the Union Address, President Barack Obama spoke to this issue, mentioning that the United States needs to offer every student hands-on computer science classes to prepare them for their future jobs (Smith, 2016). To do this, he has created a new initiative called *Computer Science for All*, a way to empower all American students in K-12 to learn CS and to "be equipped with the computational thinking skills they need to be creators in the digital economy, not just consumers, and to be active citizens in our technology-driven world" (Smith, 2016). This initiative is promising four billion dollars in funding for states to "increase access to K-12 CS by training teachers, expanding access to high-quality instructional materials, and building effective regional partnerships" (Smith, 2016). In order to empower all students and teach them CS, the focus seems to be on training teachers; involving communities, businesses and policy makers; and advancing CS locally and state-wide. Even though this initiative is aimed at CS for *all*, there is no indication that they will be focusing on promoting CS specifically for women. However, they do mention that underrepresentation of women in CS is a problem that needs to be solved.

In Canada, there has been a recent announcement that the province of British Columbia will be adding computer coding to the K-12 school curriculum over the next three years (Silcoff, 2016). However, this announcement has not come with any promises of funding for schools or teachers, nor has there been any coherent plan released on how the new curriculum will be rolled out (CBC News, 2016). From all indications, there does not seem to be any plan on helping educate new teachers in how to teach CS, or to support existing teachers. The plan also makes no mention of promoting CS to women. Unfortunately, it seems that Canada is still far behind when it comes to national reform for CS education. While there are some local and provincial initiatives to promote CS to women, there is almost no push from the national government for CS education. In fact, out of the many studies that I reviewed in which CS was promoted to high school women, most were situated in the United States, not Canada. It seems that Canada is lacking behind considerably internationally when it comes to promoting CS education to young women in high school (CBC News, 2015).

Conclusion

The lack of women in CS is a major issue within North America. This literature review has shown that an important factor affecting this issue is the low female enrolment in postsecondary CS courses. In order to recruit more young women into CS we need to dispel the stereotypes associated with CS, provide role models for women to identify with, give women more opportunities in using computers at a younger age, provide support to improve women's confidence in their computing ability, ensure that the values within CS are reflecting women's interests, and create CS learning environments which are inviting to women. While there have been many initiatives that have succeeded in increasing the enrolment of women in CS courses in post-secondary schools, most of these initiatives were localized to specific schools or universities and have only been able to affect a small number of women. In order to improve the average female CS enrolment in North America to beyond 15.3% (Zweben & Bizot, 2015), we need to have nation-wide reforms in the CS education curriculum that involve education policy makers within government. These policy makers need to introduce research-backed CS education to students at younger ages, starting in elementary and high school. They need to promote the training of qualified teachers who can teach this CS to young women. While there does seem to be a trend that indicates this may be happening, the progress thus far has been unimpressive.

This review comes at a critical time for the province of British Columbia, as there is an initiative to establish a new CS curriculum (Silcoff, 2016). This initiative is a good first step towards gender equity within CS. The information revealed here can serve as a guide to those policy makers in charge of implementing this curriculum, as well as provide valuable insight to teachers and educators that will be expected to teach CS in BC high schools. My hope is that through initiatives such as this one we can change the mind-set of North Americans, so that in ten years' time when a student is asked who the first computer programmer was, their answer will be "Ada Lovelace".

Limitations

In this review my focus was on recruitment of young women from high school into college CS courses. As mentioned previously, I also looked at women in their first year of college as many colleges allow students to declare their major after they enrol. Nevertheless, there are still many colleges that do require students to choose their majors before enrolling. Thus any suggestions on improvements to introductory CS courses, or strategies for improving CS for women will not help recruit more women in these cases. However, these strategies may still serve as a retention mechanism for women who might otherwise drop out of CS later on (Alvarado & Judson, 2014), and therefore they should not be ignored by colleges or universities when planning their CS courses.

This literature review looked specifically at the differences between men and women in CS enrolment, and did not discuss socioeconomic or ethnic differences among women, and how this would affect recruitment of women into CS. These barriers also play a role in determining who decides to enrol in CS. For example, students from poor communities are less likely to be exposed to computers and have prior experience (Simard et al., 2010), making it more likely that they will not choose CS as their major. Furthermore, studies have shown that ethnicity of female students makes a significant difference in whether they will choose to enrol in CS (Varma, 2010), and that women’s social and institutional contexts matter (Varma, 2009). Unfortunately, the scope of this study could not encompass all of these issues, but it does leave space for future study.

References

Alvarado, C., & Dodds, Z. (2010). Women in CS: an evaluation of three promising practices. *Sigcse*, (March), 57–61. doi:10.1145/1734263.1734281

Alvarado, C., & Judson, E. (2014). Using Targeted Conferences to Recruit Women into Computer Science. *Communications of the ACM*, *57*(3), 70–77. doi:10.1145/2500883

Armoni, M., & Gal-Ezer, J. (2014). High school computer science education paves the way for higher education: the Israeli case. *Computer Science Education*, *24*(2-3), 101–122. doi:10.1080/08993408.2014.936655

Asgari, S., Dasgupta, N., & Stout, J. G. (2012). When Do Counterstereotypic Ingroup Members Inspire Versus Deflate? The Effect of Successful Professional Women on Young Women's Leadership Self-Concept. *Personality and Social Psychology Bulletin*, *38*(3), 370–383. doi:10.1177/0146167211431968

Barta, T., Kleiner, M., & Neumann, T. (2012). Is there a payoff from top-team diversity? *McKinsey Quarterly*, *April*.

Bayliss, J. D. (2009). Using games in introductory courses: tips from the trenches. *40th ACM Technical Symposium on Computer Science Education*, *41*(1), 337–341. doi:10.1145/1539024.1508989

Beyer, S. (2008). Predictors of female and male Computer Science students' grades. *Journal of Women and Minorities in Science and Engineering*, (14), 377–409.

Beyer, S. (2014). Why are women underrepresented in Computer Science? Gender differences in stereotypes, self-efficacy, values, and interests and predictors of future CS course-taking and grades. *Computer Science Education*, *24*(2-3), 153–192. doi:10.1080/08993408.2014.963363

Beyer, S., & Haller, S. (2006). Gender differences and intra-gender differences in Computer Science students: Are female CS majors more similar to male CS majors or female non-majors? *Journal of Women and Minorities in Science and Engineering*, *12*(4), 337–365.

Biggers, M., Brauer, A., & Yilmaz, T. (2008). Student Perceptions of Computer Science : A Retention Study Comparing Graduating Seniors with CS Leavers. *ACM SIGCSE Bulletin*, 402–406. doi:10.1145/1352322.1352274

Blickenstaff, J. C. (2005). Women and science careers: leaky pipeline or gender filter? *Gender and Education*, *17*(4), 369–386. doi:10.1080/09540250500145072

Bloom, B. S. (1956). *Taxonomy of Educational Objectives: Cognitive Domain* (1st ed.). New York: Longmans, Green.

Blum, L., & Frieze, C. (2005). In a More Balanced Computer Science Environment, Similarity is the Difference and Computer Science is the Winner. *Computing Research News*, *17*(3), 2.

Bock, S. J., Taylor, L. J., Phillips, Z. E., & Sun, W. (2013). Women and Minorities in Computer Science Majors : Results on Barriers from Interviews and a Survey. *Issues in Information Systems*, *14*(1), 143–152.

British Columbia Ministry of Education. (2015). *BC Performance Standards*. Retrieved from http://www.bced.gov.bc.ca/perf_stands/

Brown, Q., & Briggs, A. (2015). The CS10K initiative: progress in K-12 through “exploring computer science” part 1. *ACM Inroads*, *6*(3), 52–53. doi:10.1145/2803178

Bruckman, A., Biggers, M., Ericson, B., Mcklin, T., Dimond, J., Disalvo, B., … Yardi, S. (2009). “Georgia Computes !”: Improving the Computing Education Pipeline. *Proceedings of the Special Interest Group on Computer Science Education (SIGCSE’09)*, 86–90. doi:10.1145/1539024.1508899

Bureau of Labor Statistics. (2013). Employment Projections — 2012-2022. *U.S. Department of Labor*. Retrieved from http://www.bls.gov/news.release/ecopro.toc.htm

Carter, L. (2006). Why students with an apparent aptitude for computer science don’t choose to major in computer science. *ACM SIGCSE Bulletin*, *38*(1), 27. doi:10.1145/1124706.1121352

CBC News. (2015). *Back to school: Canada lagging in push to teach kids computer coding*. *CBC/Radio-Canada*. Retrieved February 1, 2016, from http://www.cbc.ca/news/technology/back-to-school-canada-lagging-in-push-to-teach-kids-computer-coding-1.3185926

CBC News. (2016). *Christy Clark’s plan to teach coding to kids flawed says educator*. *CBC/Radio-Canada*. Retrieved February 1, 2016, from http://www.cbc.ca/news/canada/british-columbia/kids-coding-not-ready-1.3412909

Ceci, S. J., Ginther, D. K., Kahn, S., & Williams, W. M. (2014). Women in Academic Science : A Changing Landscape. *Psychological Science in the Public Interest*, *15*(3), 75–141.

doi:10.1177/1529100614541236

Chao, S. (2013). *Exploring the gender inequity in tertiary Computer Science courses : influential factors in females ' choices in Australia and Taiwan*. Monash University.

Charles, M., & Bradley, K. (2006). A Matter of Degrees: Female Underrepresentation in Computer Science Programs Cross-Nationally. In J. M. Cohoon & B. Aspray (Eds.), *Women and Information Technology: Research on the Reasons for Underrepresentation* (pp. 183–204). Cambridge, MA: MIT Press.

Cheryan, S., Drury, B. J., & Vichayapai, M. (2012). Enduring Influence of Stereotypical Computer Science Role Models on Women's Academic Aspirations. *Psychology of Women Quarterly*, *37*(1), 72–79. doi:10.1177/0361684312459328

Cheryan, S., Meltzoff, A. N., & Kim, S. (2011). Classrooms matter: The design of virtual classrooms influences gender disparities in computer science classes. *Computers & Education*, *57*(2), 1825–1835. doi:10.1016/j.compedu.2011.02.004

Cheryan, S., & Plaut, V. C. (2010). Explaining Underrepresentation: A Theory of Precluded Interest. *Sex Roles*, *63*, 475–488. doi:10.1007/s11199-010-9835-x

Cheryan, S., Plaut, V. C., Davies, P. G., & Steele, C. M. (2009). Ambient belonging: how stereotypical cues impact gender participation in computer science. *Journal of Personality and Social Psychology*, *97*(6), 1045–1060. doi:10.1037/a0016239

Cheryan, S., Plaut, V. C., Handron, C., & Hudson, L. (2013). The Stereotypical Computer Scientist: Gendered Media Representations as a Barrier to Inclusion for Women. *Sex Roles*, *69*(1-2), 58–71. doi:10.1007/s11199-013-0296-x

Cheryan, S., Siy, J. O., Vichayapai, M., Drury, B. J., & Kim, S. (2011). Do Female and Male Role Models Who Embody STEM Stereotypes Hinder Women's Anticipated Success in STEM? *Social Psychological and Personality Science*, *2*(6), 656–664. doi:10.1177/1948550611405218

Chowdhury, M., Jackson, L., & Bergen, A. (2008). Retention in Computer Science Courses. *Proceedings of the 1st CEEA Conference: Queen's University Kingston, Ontario*.

Cohoon, J. P., Cohoon, J. M., & Soffa, M. Lou. (2013). Educating diverse computing students at the University of Virginia. *Computer*, *46*(3), 52–55.

Corbett, C., & Hill, C. (2012). *Graduating to a Pay Gap: The Earnings of Women and Men One Year after College Graduation*. American Association of University Women. Retrieved from http://www.aauw.org/files/2013/02/graduating-to-a-pay-gap-the-earnings-of-women-and-men-one-year-after-college-graduation.pdf

Cozza, M. (2011). Bridging Gender Gaps, Networking in Computer Science. *Gender, Technology and Development*, *15*(2), 319–337. doi:10.1177/097185241101500207

Cuny, J. (2011). Transforming Computer Science Education in High Schools. *Computer*, *44*(6), 107–109. doi:10.1109/MC.2011.191

Denner, J., Werner, L., O'Connor, L., & Glassman, J. (2014). Community College Men and Women: A Test of Three Widely Held Beliefs About Who Pursues Computer Science. *Community College Review*, *42*(4), 342–362. doi:10.1177/0091552114535624

Denner, J., Werner, L., & Ortiz, E. (2012). Computer games created by middle school girls: Can they be used to measure understanding of computer science concepts? *Computers & Education*, *58*(1), 240–249. doi:10.1016/j.compedu.2011.08.006

Diekman, A. B., Clark, E. K., Johnston, A. M., Brown, E. R., & Steinberg, M. (2011). Malleability in communal goals and beliefs influences attraction to stem careers: Evidence for a goal congruity perspective. *Journal of Personality and Social Psychology*, *101*(5), 902–918. doi:10.1037/a0025199

Doerschuk, P., Liu, J., & Mann, J. (2011). INSPIRED High School Computing Academies. *ACM Transactions on Computing Education*, *11*(2), 1–18. doi:10.1145/1993069.1993071

Doubé, W., & Lang, C. (2012). Gender and stereotypes in motivation to study computer programming for careers in multimedia. *Computer Science Education*, *22*(1), 63–78. doi:10.1080/08993408.2012.666038

Downes, T., & Looker, D. (2011). Factors that influence students' plans to take computing and information technology subjects in senior secondary school. *Computer Science Education*, *21*(2), 175–199. doi:10.1080/08993408.2011.579811

DuBow, W. M., Vakalis, I., Perez-Quinones, M. A., & Black, J. T. (2013). Growing female undergraduate enrollments in computer science. *Proceeding of the 44th ACM Technical Symposium on Computer Science Education - SIGCSE '13*, 377. doi:10.1145/2445196.2445306

Eccles, J. S., Barber, B., & Jozefowicz, D. (1999). Linking gender to educational, occupational, and recreational choices: Applying the Eccles et al. model of achievement-related choices. In W. B. S. Jr & J. H. Langlois (Eds.), *Sexism and stereotypes in modern society: The gender science of Janet Taylor Spence* (pp. 153–192). Washington: American Psychological Association.

Edery, D., & Mollick, E. (2009). *Changing the game: how video games are transforming the future of business*. Upper Saddle River, N.J: FT Press.

Eidelman, L., Hazzan, O., Lapidot, T., Matias, Y., Raijman, D., & Segalov, M. (2011). Mind the (gender) gap: Can a two-hour visit to a hi-tech company change perceptions about computer science? *ACM Inroads*, *2*(3), 64–70. doi:10.1145/2003616.2003637

Eney, C., Lazowska, E., Martin, H., & Reges, S. (2013). Broadening participation: The why and the how. *Computer*, *46*(3), 48–51. doi:10.1109/MC.2013.83

Entertainment Software Association. (2015). 2015 Essential Facts About the Computer and Video Game Industry.

Faisal, S., Asliturk, E., Bourgi, S., Savard, A., Aquilina, A., & Castillo, D. Del. (2015). *The Smart Economy Reshaping Canada's Workforce: Labour Market Outlook 2015—2019*.

Franklin, D. (2013). *A Practical Guide to Gender Diversity for Computer Science Faculty*. (C. X. Ling & Q. Yang, Eds.)*Synthesis Lectures on Professionalism and Career Advancement for Scientists and Engineers* (Vol. 1). Morgan & Claypool. doi:10.2200/S00495ED1V01Y201304PRO002

Frieze, C., & Quesenberry, J. L. (2013). From Difference to Diversity : Including Women in The

Changing Face of Computing. *Proceeding of the 44th ACM Technical Symposium on Computer Science Education - SIGCSE ’13*, 445–450.

Gal-Ezer, J., & Stephenson, C. (2009). The Current State of Computer Science in U. S. High Schools : A Report from Two National Surveys. *Journal for Computing Teachers*, (Spring), 1–5.

Gal-Ezer, J., & Stephenson, C. (2010). Computer Science Teacher Preparation is Critical. *ACM Inroads*, *1*(1), 61–66.

Gannod, G. C., Burge, J. E., McIe, V., Doyle, M., & Davis, K. C. (2014). Increasing awareness of computer science in high school girls. In IEEE (Ed.), *2014 IEEE Frontiers in Education Conference (FIE) Proceedings* (pp. 1–8). Madrid. doi:10.1109/FIE.2014.7044456

Gharibyan, H., & Gunsaulus, S. (2006). Gender gap in computer science does not exist in one former soviet republic. *ACM SIGCSE Bulletin*, *38*(3), 222. doi:10.1145/1140123.1140184

Government of Alberta. (2015). *Programs of Study*. Retrieved from http://www.education.alberta.ca/teachers/program.aspx

Hango, D. (2013). Gender differences in science, technology, engineering, mathematics and compuer science (STEM) programs at university. *Statistics Canada*.

He, J., & Freeman, L. (2010). Are men more technology-oriented than women? The role of gender on the development of general computer self-efficacy of college students. *Journal of Information Systems Education*, *21*(2), 203–213.

Herring, C. (2009). Does Diversity Pay?: Race, Gender, and the Business Case for Diversity.

American Sociological Review, *74*(2), 208–224. doi:10.1177/000312240907400203

Horn, L. J., Premo, M. D., & Malizio, A. G. (1995). *Profile of Undergraduates in U.S. Postsecondary Education Institutions: 1992-93*.

Hubwieser, P. (2012). Computer science education in secondary schools–the introduction of a new compulsory subject. *ACM Transactions on Computing Education (TOCE)*, *12*(4), 16. doi:10.1145/2382564.2382568

Isaacson, W. (2015). *The Innovators: How a Group of Hackers, Geniuses, and Geeks Created the Digital Revolution*. Simon & Schuster.

Kafai, Y. B., Heeter, C., Denner, J., & Sun, J. Y. (2008). *Beyond Barbie and Mortal Kombat: new perspectives on gender and gaming*. Cambridge, MA: MIT Press.

Kelleher, C., Pausch, R., & Kiesler, S. (2007). Storytelling alice motivates middle school girls to learn computer programming. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '07*, 1455. doi:10.1145/1240624.1240844

Klawe, M. (2013). Increasing female participation in computing: The Harvey Mudd college story. *Computer*, *46*, 56–58.

Koch, S. C., Müller, S. M., & Sieverding, M. (2008). Women and computers. Effects of stereotype threat on attribution of failure. *Computers and Education*, *51*, 1795–1803. doi:10.1016/j.compedu.2008.05.007

Kordaki, M., & Berdousis, I. (2014). Course Selection in Computer Science: Gender Differences. *Procedia - Social and Behavioral Sciences*, *116*, 4770–4774.

doi:10.1016/j.sbspro.2014.01.1023

Lagesen, V. A. (2007). The Strength of Numbers: Strategies to Include Women into Computer Science. *Social Studies of Science*, *37*(1), 67–92. doi:10.1177/0306312706063788

Lagesen, V. A. (2008). A Cyberfeminist Utopia? Perceptions of Gender and Computer Science among Malaysian Women Computer Science Students and Faculty. *Science, Technology, & Human Values*, *33*(1), 5–27.

Lang, C. (2010). Happenstance and compromise: a gendered analysis of students' computing degree course selection. *Computer Science Education*, *20*(4), 317–345. doi:10.1080/08993408.2010.527699

Lang, K., Galanos, R., Goode, J., Seehorn, D., Trees, F., Phillips, P., & Stephenson, C. (2013). *Bugs in the System: Computer Science Teacher Certification in the U.S.* Association for Computing Machinery and Computer Science Teachers Association.

Leutenegger, S., & Edgington, J. (2007). A games first approach to teaching introductory programming. *Proceedinds of the 38th SIGCSE Technical Symposium on Computer Science Education - SIGCSE '07*, *March*, 115. doi:10.1145/1227310.1227352

Lockard, C. B., & Wolf, M. (2012). Employment outlook: 2010–2020. *Monthly Labor Review*, *135*(1), 84–108.

Looker, D., & Thiessen, V. (2003). *The digital divide in Canadian schools : factors affecting student access to and use of information technology*. Ottawa: Statistics Canada.

Margolis, J., & Fisher, A. (2002). *Unlocking the clubhouse: Women in computing*.

Mishra, S., Draus, P., Caputo, D., Leone, G., Kohun, F., & Repack, D. (2014). Gender Rationales in Selecting a Major in Information Technology at the Undergraduate level of a University Program: A Focus Group Approach. *Information Systems Education Journal*, *12*(4), 40–47.

National Science Foundation, & National Center for Science and Engineering Statistics. (2015). *Women, Minorities, and Persons with Disabilities in Science and Engineering: 2015 Digest*. *Special Report NSF*. Arlington, VA. Retrieved from http://www.nsf.gov/statistics/wmpd/

Nye, C. D., Su, R., Rounds, J., & Drasgow, F. (2012). Vocational Interests and Performance: A Quantitative Summary of Over 60 Years of Research. *Perspectives on Psychological Science*, *7*(4), 384–403. doi:10.1177/1745691612449021

Ochwa-Echel, J. (2011). Exploring the Gender Gap in Computer Science Education in Uganda. *International Journal of Gender, Science and Technology*, *3*(2), 273–292.

Ogan, C., Robinson, J. C., Ahuja, M., & Herring, S. C. (2006). Gender differences among students in computer science and applied information technology. In J. M. Cohoon & W. Aspray (Eds.), *Women and information technology: Research on underrepresentation* (pp. 279–300). Cambridge, MA: MIT Press.

Ontario Ministry of Education. (2015). *What do you need to graduate?* Retrieved from http://www.edu.gov.on.ca/extra/eng/ppm/graduate.html

Othman, M., & Latih, R. (2006). Women in Computer Science: No Shortage Here! *Communications of the AGM*, *49*(3), 111–114. doi:10.1145/1118178.1118185

Pivkina, I., Pontelli, E., Jensen, R., & Haebe, J. (2009). Young women in computing: lessons learned from an educational & outreach program. *SIGCSE Bull.*, *41*, 509–513. doi:10.1145/1539024.1509042

Pollock, L., McCoy, K., Carberry, S., Hundigopal, N., & You, X. (2004). Increasing High School Girls' Self Confidence and Awareness of CS Through a Positive Summer Experience. *Proceedings of the 35th SIGCSE Technical Symposium on Computer Science Education,* 185–189. doi:10.1145/971300.971369

Powell, R. M. (2008). Improving the persistence of first-year undergraduate women in computer science. *ACM SIGCSE Bulletin*, *40*. doi:10.1145/1352322.1352308

Redmond, K., Evans, S., & Sahami, M. (2013). A large-scale quantitative study of women in computer science at Stanford University. *Proceeding of the 44th ACM Technical Symposium on Computer Science Education - SIGCSE '13*, 439– 444. doi:10.1145/2445196.2445326

Roach, D., McGaughey, R. E., & Downey, J. P. (2011). Gender within the IT major – A retrospective study of factors that lead students to select an IT major. *International Journal of Business Information Systems, 7*(2), 149–165.

Robertson, J. (2013). The influence of a game making project on male and female learners ' attitudes to computing. *Computer Science Education*, *23*(1), 58–83. doi:10.1080/08993408.2013.774155

Rommes, E., Overbeek, G., Scholte, R., Engels, R., & De Kemp, R. (2007). "I'M NOT

INTERESTED IN COMPUTERS”: Gender-based occupational choices of adolescents. *Information, Communication & Society*, *10*(3), 299–319. doi:10.1080/13691180701409838

Rosson, M. B., Ioujanina, A., Paone, T., Sheasley, G., Sinha, H., Ganoe, C., … Mahar, J. (2009). A scaffolded introduction to dynamic website development for female high school students. *Sigcse ’09*, *41*(1), 226–230. doi:10.1145/1539024.1508950

Sáinz, M., & Eccles, J. S. (2012). Self-concept of computer and math ability: Gender implications across time and within ICT studies. *Journal of Vocational Behavior, 80*(2), 486–499. doi:10.1016/j.jvb.2011.08.005

Sariffodeen, M. (2015). *We broke the internet at Girls Learning Code Day 2015*. *Ladies Learning Code*. Retrieved from http://ladieslearningcode.com/we-broke-the-internet-at-girls-learning-code-day-2015/

Saujani, R. (2015). *Girls Who Code - 2014 in review*. *Girls Who Code*. Retrieved from http://girlswhocode.com/2014report/

Schifter, C., & Cipollone, M. (2013). Minecraft as a teaching tool: One case study. *Proceedings of Society for Information Technology & Teacher Education International Conference 2013*, 2951–2955.

Seehorn, D., Carey, S., Fuschetto, B., Lee, I., Moix, D., O’Grady-Cuniff, D., … Verno, A. (2011). *CSTA K-12 Computer Science Standards*. Computer Science Teachers Association.

Seymour, E., & Hewitt, N. M. (1997). *Talking about leaving : why undergraduates leave the sciences*. Boulder, Colo. : Westview Press.

Silcoff, S. (2016). *B.C. to add computer coding to school curriculum*. *The Globe and Mail*. Retrieved June 20, 2002, from http://www.theglobeandmail.com/technology/bc-government-adds-computer-coding-to-school-curriculum/article28234097/

Simard, C., Stephenson, C., & Kosaraju, D. (2010). *Addressing Core Equity Issues in K-12 Computer Science Education: Identifying Barriesr and Sharing Strategies*. The Anita Borg Institute and Computer Science Teachers Association.

Singh, K., Allen, K. R., Scheckler, R., & Darlington, L. (2007). Women in Computer-Related Majors: A Critical Synthesis of Research and Theory From 1994 to 2005. *Review of Educational Research*, *77*(4), 500–533. doi:10.3102/0034654307309919

Smith, M. (2016). *Computer Science For All*. *The Whitehouse Blog*. Retrieved February 1, 2016, from https://www.whitehouse.gov/blog/2016/01/30/computer-science-all

Snyder, T. D., & Dillow, S. A. (2015). *Digest of Education Statistics, 2013*. *NCES 2015-011*. National Center for Education Statistics, Institute of Education Sciences, U.S. Department of Education. Washington, DC.

Statistics Canada. (2016). *Table 477-0019 - Postsecondary enrolments, by registration status, Pan-Canadian Standard Classification of Education (PCSCE), Classification of Instructional Programs, Primary Grouping (CIP_PG), sex and immigration status, annual (number)*. *CANSIM (database)*. Retrieved June 20, 2002, from http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=4770019&tabMode=dataTable&srchLan=-1&p1=-1&p2=9

Stephenson, C., & Dovi, R. (2013). More than Gender : Taking a Systemic Approach to Improving K-12 Computer Science Education. *Computer*, (March), 42–46.

Stoilescu, D., & Egodawatte, G. (2010). Gender differences in the use of computers, programming, and peer interactions in computer science classrooms. *Computer Science Education*, *20*(4), 283–300. doi:10.1080/08993408.2010.527691

Stoilescu, D., & McDougall, D. (2011). Gender digital divide and challenges in undergraduate computer science programs. *Canadian Journal of Education*, *34*(1), 308–333.

Su, R., Rounds, J., & Armstrong, P. I. (2009). Men and things, women and people: a meta-analysis of sex differences in interests. *Psychological Bulletin*, *135*(6), 859–884. doi:10.1037/a0017364

Sung, K. (2009). Computer games and traditional CS courses. *Communications of the ACM*, *52*(12), 74. doi:10.1145/1610252.1610273

Sydell, L. (2014). *The Forgotten Female Programmers Who Created Modern Tech*. Retrieved February 1, 2016, from http://www.npr.org/sections/alltechconsidered/2014/10/06/345799830/the-forgotten-female-programmers-who-created-modern-tech

The Association of Universities and Colleges of Canada. (2011). *Trends in Higher Education. Volume 1 - Enrolment*. doi:10.2307/1974977

The College Board. (2014a). *Annual AP Program Participation 1956-2014*. Retrieved from http://media.collegeboard.com/digitalServices/pdf/research/2014/2014-Annual-

Participation.pdf

The College Board. (2014b). *AP Exam Volume by Region 2014*. Retrieved from http://media.collegeboard.com/digitalServices/pdf/research/2014/Volume-by-Region-2014.pdf

The College Board. (2014c). *Program summary report*. Retrieved from http://media.collegeboard.com/digitalServices/pdf/research/2014/Prog-Summary-Report-2014.pdf

Truong, C., & O'Brien, B. (2016). *Girls Learning Code*. *Ladies Learning Code*. Retrieved from http://ladieslearningcode.com/program/girls-learning-code/

Tucker, A., McCowan, D., Deek, F., Stephenson, C., Jones, J., & Verno, A. (2006). *A model curriculum for K-12 computer science: Report of the ACM K-12 task force computer science curriculum committee* (2nd ed.). New York, NY: ACM.

U.S. Department of Education. (2015). *Definitions*. Retrieved from http://eddataexpress.ed.gov/definitions.cfm

UBC Department of Computer Science. (2016a). *Awards & Scholarships*. Retrieved February 1, 2016, from https://www.cs.ubc.ca/students/undergrad/resources/awards-and-scholarships

UBC Department of Computer Science. (2016b). *Statistics*. Retrieved February 1, 2016, from https://www.cs.ubc.ca/our-department/women/statistics

Van Eck, R. (2006). Digital Game-Based Learning: It's Not Just the Digital Natives Who Are Restless. *EDUCAUSE Review*, *41*(2), 16–30. doi:10.1145/950566.950596

Varma, R. (2009). Gender differences in factors influencing students towards computing. *Computer Science Education*, *19*(1), 37–49. doi:10.1080/08993400902819006

Varma, R. (2010). Why so few women enroll in computing? Gender and ethnic differences in students' perception. *Computer Science Education*, *20*(4), 301–316. doi:10.1080/08993408.2010.527697

Varma, R. (2011). Indian Women and Mathematics for Computer Science. *IEEE Technology and Society Magazine*, *30*(1), 39–46. doi:10.1109/MTS.2011.940294

Varol, H., & Varol, C. (2014). Improving Female Student Retention in Computer Science during the First Programming Course. *International Journal of Information and Education Technology*, *4*(5), 394–398. doi:10.7763/IJIET.2014.V4.437

Vygotsky, L. S., & Cole, M. (1978). *Mind in society: The development of higher psychological processes*. Cambridge: Harvard University Press.

Warren, S. J. (2015). Games: Impact on Learning. In M. J. Spec (Ed.), *The SAGE Encyclopedia of Educational Technology Vol. 2* (pp. 299–302). SAGE Publications.

Webb, D. C., Repenning, A., & Koh, K. H. (2012). Toward an emergent theory of broadening participation in computer science education. *SIGCSE '12 Proceedings of the 43rd ACM Technical Symposium on Computer Science Education*, 173–178. doi:10.1145/2157136.2157191

Weinberger, C. J. (2006). Earnings of Women with Computer Science or Engineering College Majors. In *Encyclopedia of gender and information technology* (pp. 224–227). Hershey, PA: Idea Group Inc.

Weisgram, E. S., Dinella, L. M., & Fulcher, M. (2011). The Role of Masculinity/Femininity, Values, and Occupational Value Affordances in Shaping Young Men's and Women's Occupational Choices. *Sex Roles*, *65*(3), 243–258. doi:10.1007/s11199-011-9998-0

Wilson, C., Sudol, L. A. S., Stephenson, C., & Stehlik, M. (2010). *Running on empty: The Failure to Teach K-12 Computer Science in the Digital Age*. Association for Computing Machinery and Computer Science Teachers Association.

Zarret, N., Malanchuk, O., Davis-Kean, P. E., & Eccles, J. S. (2006). Examining the gender gap in IT by Race: Young Adult's Decisions to Pursue an IT Career. In J. M. Cohoon & W. Aspray (Eds.), *Women and Information Technology - Research on Underrepresentation* (pp. 55–88). Cambridge, MA: MIT Press.

Zeffertt, M., Thinyane, H., & Halse, M. (2014). Investigating the Use of Games for Creating a Contextualized and Gender Inclusive Computer Science Curriculum. In *ICERI2014 Proceedings* (pp. 4797–4804).

Zhang, W. (2007). Why IS: Understanding Undergraduate Students ' Intentions to Choose an Information Systems Major. *Journal of Information Systems Education*, *18*(4), 447–458. doi:Article

Zweben, S., & Aspray, W. (2004). 2002-2003 Taulbee Survey. *Computing Research News*, 5–19.

Zweben, S., & Bizot, B. (2014). 2013 Taulbee Survey. *Computing Research News*, *26*(5), 10–55.

Zweben, S., & Bizot, B. (2015). 2014 Taulbee Survey. *Computing Research News*, *27*(5).