Explaining Gendered Participation in Computer Science Education

by

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Abstract

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Amongst scientific fields, computer science (CS) is the only one in which the percentage of women undergraduates has decreased since the 1980s; in the US and Canada, this percentage has hovered around 15%. Since the 1990s, a great deal of effort and resources have been put toward trying to improve the representation of women in computing. Unfortunately, these wide-spread efforts have not resulted in any macro-scale improvements.

Using theoretical and conceptual tools from critical sociology, policy analysis, and systems thinking, I examine the question of why the efforts to improve gender diversity in CS education have not had a more discernible effect on a macro scale. I begin by classifying gender diversity initiatives, and observe that the most prevalent types of initiatives are low-leverage. I examine the history of women in computing, finding that enrolment booms are key times for gendering participation: when universities faced enrolment booms in the late 1980s and dot-com era, the percentage of women decreased, in part from gatekeeping measures enacted by CS departments. And as CS is currently facing its third enrolment boom, I survey CS faculty to see what factors are influencing their current policy discussions about enrolments. I find that diversity is seldom considered, nor is history; this approach to policymaking could exacerbate the gendered participation in CS.

I also extend Etzkowitz et al.s framework of "generations" of women in STEM, noting that different generations of women in CS have had differing and conflicting goals for gender equality. Through re-examining the historical variations in gendered participation in computing, and considering the contemporanous global variations, I determine that Anne Witzs occupational closure theory provides an explanation for the historico-geographical variations. I find that policies (e.g. educational gatekeeping) and discourses (e.g. you need to be brilliant to be a computer scientist) are the primary ways in which the boundaries of CS are closed.

For CS to improve its gender diversity, we need to make higher leverage changes; identifying policies and discourses as critical levers allows for change-agents to more effectively push for gender diversity.

For all the women who wanted to major in CS but were told they could not transfer into the field.

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Chapter 0

How To Read This Thesis

This thesis is written in the portfolio style: a series of papers on my research topic, with bookending chapters and some coupling text in between.

The publications are organized approximately chronologically by when I did the bulk of the work on the paper. As a result, reading the whole thing from start to finish will give the reader a sense of my intellectual journey.

There are three ways I would recommend reading this document, depending on one's goals:

1. **To get a quick understanding of the main takeaways of this corpus, with a minimal time commitment**
    (a) Read the abstract
    (b) Read chapter 5 as an introduction/background
    (c) Read chapter 4 to get a sense of the empirical work I did and its implications for educators and policy makers
2. **To get a fuller understanding of the main research findings of this corpus**, perhaps because you started the option above and then wanted more.
    (a) Read the abstract
    (b) Read chapter 5 as an introduction/background
    (c) Read chapter 4 and chapter 6 for substantive findings
    (d) Read chapter 7 to cap it off
3. **To observe the journey I went on in my PhD**
    (a) Just read it start to finish!

Chapter 1

Introduction

Computer science has a reputation for being a "boys' club" [136]. Women are underrepresented in the field and frequently describe feeling unwelcome, or experiencing outright sexism [35]. At the same time, a lot of effort has been put into trying to making computing a more welcoming place for women. So why is it that the percentage of women in computing in the US and Canada has remained persistently low in the last two decades, when there is so much effort being put into changing it?

The percentage of women enrolled in a Bachelor's program in the US and Canada has stubbornly remained around 15%. But geography and history teach us that this isn't fate: computing was initially female-dominated [2], and in the 1980s women comprised 40% of CS majors in the US [8]; furthermore, the percentage of women varies globally, with women comprising nearly 50% of CS majors in India [154] and 60% in Malaysia [144].

We also have evidence that change can happen in the present-day West, through the examples of Carnegie Mellon University [136] and Harvey Mudd College [6], both of which made significant changes in their undergraduate CS programmes that led to around 40% female students. So why aren't all universities following suit?

The question of why gender diversity initiatives in computing have not had more wide-spread success is a complex question. Over the years I have looked at the question through different theoretical lenses and with different methods.

Each of the chapters of this thesis provides a different perspective on this question, and I have organized the chapters to reflect the different perspectives I have explored during my intellectual journey. Early chapters reflect an orientation towards social psychology and structuralist systems thinking; later chapters demonstrate my shift toward critical sociology and poststructuralism.

Each of these perspectives can only provide a partial view of the world. Influenced by Haraway's notion of partial perspectives [104], I identify for the reader the various perspectives I held, how I came to that perspective, and what it got me. Haraway argues that no perspective can ever provide a complete or perfect view of objectivity, and that a feminist approach to science must appreciate one's limited location and the situated nature of knowledge.

With such a complex question to investigate, it was necessary for me to establish some boundaries on its scope. In this thesis I focus on women in computing in the US and Canada at the undergraduate level. I also work with a binary notion of gender, which future work would need to address.

1.1 Background

1.1.1 Women in Computing as a Wicked Problem

The term *wicked problem* is used in discussions of policy to refer to a class of problems which are ill-specified and difficult — if not impossible — to solve. More specifically, Rittel and Webber define a wicked problem as having the following ten characteristics [167], each of which are present in the context of improving female participation in computing.

1. **There is no definitive formulation of a wicked problem.** Are we trying to improve the percentage of women in computing? Or the total number of women in computing? And at what point: intake, graduation, work? What do we include as "computing"? (E.g., do cognitive science students count?) Or are we concerned with the experiences of women in computing, such a reducing bias, harassment, etc?

2. **Wicked problems have no stopping rule.** If we have 50% women in CS, have we succeeded? Particularly if issues such as bias and harassment still continue? And returning to #1, how are we even measuring that?

3. **Solutions to wicked problems are not true-or-false, but better or worse.** Whether we have solved "women in computing" fits this characteristic.

4. **There is no immediate and no ultimate test of a solution to a wicked problem.** Again, this is true of our problem.

5. **Every solution to a wicked problem is a "one-shot operation"; because there is no opportunity to learn by trial and error, every attempt counts significantly.** At first glance, our problem does not clearly satisfy this characteristic — CS departments, companies, etc, do have opportunity to learn through trial and error. However, Rittel and Webber go on to explain that "every implemented solution is consequential. It leaves 'traces' that cannot be undone ... And every attempt to reverse a decision or correct for the undesired consequences poses yet another set of wicked problems" [167]. This is indeed the case for women in computing: policies and initiatives will change the system and affect what comes thereafter.

6. **Wicked problems do not have an enumerable (or an exhaustively describable) set of potential solutions, nor is there a well-described set of permissible operations that may be incorporated into the plan.** The solution space for this problem is large, if not infinite.

7. **Every wicked problem is essentially unique.** While the situation of women in computing is similar to that of women in other male-dominated fields (e.g., physics), computing has a history that is unique compared to these fields [109].

8. **Every wicked problem can be considered to be a symptom of another problem.** Some would see the gendering of computing as a result of the existence and enforcement of societal gender roles. Others may point to other societal problems; e.g., Sturman considers it a symptom of neoliberal capitalism [193].

9. **The existence of a discrepancy representing a wicked problem can be explained in numerous ways. The choice of explanation determines the nature of the problem's**

resolution. For example, explaining women's low participation in computing as a result of lack of early exposure would imply that one should provide early exposure (or better pathways for late-comers), whereas explaining the participation as a result of gender roles would imply that the nature of gender roles should be addressed.

10. **The social planner has no right to be wrong (i.e., planners are liable for the consequences of the actions they generate).** In many "pure" scientific studies, the researcher can make a hypothesis and then have the hypothesis refuted by others without penalty. Those who participate in policy processes and equity initiatives do not have the luxury of just being incorrect; given the consequences that a policy/initiative may have there is a moral imperative to "get it right."

Since wicked problems have, by definition, differing formulations and underlying causes, it is important for a researcher to clarify and identify their theoretical understanding of the problem. Because I am studying a social phenomenon, social theory is an important tool for my work.

1.1.2 Social Theories

Theory provides a lens for studying social phenomena. A photography metaphor is apt for explaining why different theories can be useful: different theories will place different features in the foreground or background — or may not even have them in "the frame" at all.

Classical social theory

Classically, sociology has had four major schools of thought, each of which goes by various names and is associated with one of the four "founders" of sociology [78]:

1. August Comte (1798–1857) [78] coined the term "positive philosophy", now better known as **positivism**. Comte"s sociology was inspired by the French Revolution: sociology was envisioned as a means to produce the perfect society. One would test out different ideas for how to run a society, and find the optimal approach. While Comte himself argued for holism, (post)positivism has since come to be associated with reductionism.

2. The sociology of Max Weber (1864–1920) [78] contrasts with Comte's: Weber was a proponent of anti-positivism (also known as **constructivism** or interpretivism). Weber saw *verstehen* (understanding) as the goal of research, rather than hypothesis verification. Weber theorized upon social stratification; he also wrote about closure (how groups draw the boundaries and construct identities, and compete with out-group members for scarce resources.)

3. Émile Durkheim (1858–1917) [78] built on Comte's positivism, setting forth **structural functionalism**. In structural functionalism, a society is viewed like a biological cell: different parts of a society are likened to organelles. Durkheim's sociology looks at how the parts work together to comprise the whole. It is also holistic; much of how systems thinking was used in the social sciences built on Durkheimian notions of society.

4. Finally, Karl Marx (1818–1883) [78] provided an approach which contrasts with Durkheim's: instead of seeing harmony, it emphasizes the role of class conflict in society and the historical-economic basis thereof. Marxist sociology has also been known as **conflict theory**. Critical

theory is also based on Marxist thought, and emphasizes *praxis*, the combination of theory and practice. Contemporary conflict theory often bases itself on schools of thought that can trace themselves back to both Marx and Weber. Neo-Marxism refers to the 20th century updates of Marxist theory, which has pulled in Weberian and poststructuralist work on status and power.

Contemporary social theory

A few schools of thought which emerged in the 20th-century that are worth noting are:

5. **Interactionism** assumes that all social processes are the result of human interaction. It emerged in the early 20th century. Interactionists focus their studies on the interactions between individuals. As a result, interactionists do not "see" the effects of physical environment – or even solitary thought/work. They also reject quantitative data in favour of qualitative approaches: grounded theory and ethnomethodology were both developed by interactionists. The notion of social interaction as a performance was first developed in interactionist thought; poststructuralists have since refined it. While there's no single name associated with this perspective, some associated names include George Herbert Mead and Erving Goffman.

   Sociologists also look at social systems at different levels: the *macro* level looks at entire societies, nations, etc; the *meso* level looks at organizations, institutions, etc; and the *micro* level looks at individuals. While classical sociology generally focused on macro-level analysis, interactionism focuses on the micro level.

   In my thesis I focus on the *meso* and *macro* levels, which is relatively uncommon in CS education. Most (though not all) CS education research targets the micro level.

6. **Structuralism** sees social processes as stemming from larger, overarching structures, and also emerged in the early 20th century. Structuralists see society as being governed by these structures in a somewhat analogous fashion to how physicists may see the universe as being governed by laws of nature. A criticism of structuralism is that it sees these structures as fixed; in contrast, a Marxist would focus on historical change. Some structuralists include Claude Lévi-Strauss, Ferdinand de Saussure, and Jean Piaget.

7. **Poststructuralism** (more or less interchangeable with "postmodernism") evolved from structuralism, and reflects a cynicism that the structuralist enterprise could ever be accomplished. Poststructuralists reject the idea of "objective" knowledge: since the study of sociology is done by humans who are biased by history and culture, they argue that any study of a social phenomenon must be combined with how the study of that social phenomenon was produced. For example, a poststructuralist would not take a concept like "gender" as a given, but problematize the concept. Poststructuralism evolved out of structuralism in the mid 20th century. Some major poststructuralists include Michel Foucault, Jacques Derrida, and Judith Butler.

   It is often useful to think of a spectrum from structuralism to poststructuralism where many scholars fall somewhere in the middle. Indeed, many prominent poststructuralists reject the label [78].

Feminist theory

Like social theory, there are numerous approaches to feminist theory. The perspective you use will influence the research questions you pose, and what you focus upon in your analysis. The common thread of feminist theory is that women should have equality in society. Studying women in CS is not necessarily feminist; to be feminist, the goal of social justice is key[1]. There exist several major approaches to feminism:

1. **Liberal feminists** argue that society holds the false belief that women are less capable than men, and as a result tends to discriminate against women in institutions such as education, politics and finance [87]. Liberal feminists assume that moderate reforms will secure the liberation of women, and that "the structure of the state, the economy, and the family do not need to be fundamentally changed."[87] Most feminist theories begin with critiques of liberal feminism [87].

   Perhaps because CS education researchers often do not have backgrounds in gender studies, liberal feminism is the most common approach to studying women in CS: looking at biases facing women in the field and arguing to mitigate these biases. Small-scale and small-leverage changes are considered acts of success, such as changing the self-efficacy of some women, or creating a CS0 for female students.

2. **Radical feminists** argue that the oppression of women by men is due to a system ("patriarchy") which is an oppressive family structure which controls the sexuality and reproductive capacities of women [87].

3. **Marxist feminists** argue that women are oppressed due to the system of capitalism, rather than through patriarchy. In Marxist feminist thought, the capitalist system relies on the uncompensated domestic labour of women. While a traditional Marxist would foreground class conflict in society, a Marxist feminist would foreground gender-based conflict.

   From a systems-thinking perspective, radical and Marxist feminists are much more concerned with higher-leverage issues than are liberal feminists. A radical/Marxist feminist would be interested in the role of patriarchy/capitalism in preventing women from studying computer science. For example, given the involvement of capital, a Marxist would ask questions about the role of companies like Google in promoting diversity in CS education.

4. **Socialist feminists** agree with radical and Marxist feminists that liberal feminism does not account for the depth of the oppression of women in social systems [87]. Socialist feminists also incorporate the critiques of liberal feminism by Black feminists that liberal feminism only addresses the concerns of upper- and upper-middle-class white women [87]. Socialist feminists think that the oppression of women is based on both the capitalist system and the patriarchal system. As a result, some theorists, like Walby, hence call it "dual systems theory" [211].

   A defining difference between socialist feminism versus Marxist and radical feminisms is that socialist feminists do not believe that any one form of oppression is the *most* important or key form of oppression [87]. To socialist feminists, sexism, racism, classism, and other forms of oppression

[1]For example, Sheryl Sandberg has been criticized for promoting women in IT for business purposes, rather than for social justice. [7]. Others have documented cases of men trying to improve the participation of women in computing so that they could "find somebody to date" [35].

are all interwoven and different aspects of the same problem (oppression). As a result, to challenge any one of these forms of oppression, we must understand and challenge all of them [87].

5. **Cultural feminists** are concerned with how feminine traits and approaches to socializing are devalued; they counter this by positively presenting feminine traits. Carol Gilligan's "ethic of care" is a popular work here here; values such as caring and social connection are presented as more important than the dominant masculine values of competition and rights. This brand of feminism has been heavily critiqued. For example, bell hooks described it as the "romanticization of powerlessness" [43]. Also problematic is that it presents the experiences and values of white Western women as that of all women (*"universalizing"*).

   Perhaps the most common critique is that it is *essentialist*: it assumes that there is some essential quality that is common to all women and not in men. Assuming that women are inherently more caring than men is an example of an essentialist assumption. Essentialism is contrasted with gender constructionism: the notion that gender is something that society constructs, rather than something that is inherent.

6. **Poststructural feminists** problematize the very concept of "woman". How does one define "woman?" How do people outside the gender binary fit in? What makes a "woman" a woman? The very notion that there is an objective definition of "woman," to a postmodernist, is not only problematic, but this assumption reifies existing inequalities. Poststructural feminists are anti-essentialist, and see gender as a performance: it is something that one *does* rather than something that one *has*.

   Poststructuralists similarly critique "race" for being an ill-defined construct [102]. Critical theorists such as George Dei, however, object to putting race in quotes: while the boundaries of race are ill-defined, race has a clear effect on people's lived experiences, and its role should not be trivialized [60]. Poststructuralism has also been criticized for being too academic, for focusing on linguistic and philosophical questions rather than producing applicable knowledge [87].

Once again, schools of thought can be hybridized. It is common for contemporary Marxist/socialist feminists to pull in poststructural thought: when examining gender-based conflict, they also see gender as a socially constructed performance. But while a poststructural feminist would dwell on how this social construction occurs, a Marxist/socialist would instead focus on how it plays out on the real world and in lived experiences. While I agree with poststructural feminists that gender is a problematic concept with fuzzy boundaries, this lens seems ill-suited to a focus on why women aren't studying CS in larger numbers. Women who report on their experience in CS do find that their experiences are affected by their gender; it is a real thing to them.

1.2 Portfolio Format

This thesis is organized as a portfolio thesis: a collection of peer reviewed articles with a unifying theme. While three articles are often the norm for a portfolio thesis, I present five, with the note that one is a short article, and another is a revised version of an earlier article in the collection.

Chapter 2. *Scaling up Women in Computing Initiatives: What Can We Learn from a Public Policy Perspective?* (ICER 2015) was my first serious effort at examining my central question of why gender diversity initiatives have had not had more apparent success. I had been recently introduced to systems thinking and used Donella Meadows' framework of leverage points to argue that the typical initiatives such as women in computing lunches are low leverage — and hence don't change the system. As I learned more about systems thinking, I discovered Checkland's soft systems thinking, a methodology in which looking at the history of a social system is a key early step.

Chapter 3. *A Historical Examination of the Social Factors Affecting Female Participation in Computing* (ITiCSE 2014) reflected my realization that I needed to understand the historical context in order to properly tackle my central question. In this article, I provide a literature review of the history of women in computing from the 19th century to the present day. In organizing the literature review, I found it helpful to use Etzkowitz et al.'s framework of generations of women in science: the first generation of women in a scientific field experience it differently than the women who enter the field after some women have already established themselves [68]. I added a third generation to the framework: the women who arrive once there are already formalized gender-diversity efforts.

In studying the history of women in computing, I found that enrolment booms in undergraduate computing have historically been key events. When enrolments boomed in the late 1980s, women were disproportionately affected by gatekeeping policies used to manage enrolments, resulting in women going from 40% of CS majors to 25%. The enrolment boom in the dot-com era provided a repeat of this phenomenon, bringing the percentage down to its present-day 15%. At the time I wrote the article (2013), enrolments were beginning to boom a third time, raising concerns that this phenomenon would repeat itself.

Chapter 4. *How CS Departments are Managing the Enrolment Boom: Troubling Implications for Diversity* (RESPECT 2016) is a short paper in which I describe the results of a survey I conducted of 78 CS professors across North America about how their CS department has been responding to the contemporary enrolment boom. Notable findings included that CS education literature was not on the radar in any of my participants' departments, and that only one participant reported that diversity was playing a role in their department's policy making.

Chapter 5. *Gendered Participation in Computing Education: What Educators Should Know About The Historical Sociological Trends* (currently under review for publication) is a rewrite of my earlier ITiCSE 2014 literature review of the history of women in computing. I decided to update this paper in order to incorporate new historical texts which were published after my ITiCSE paper was written, as well as to add in the theoretical understanding that I had been developing since.

After finding micropolitics did not play the role I'd expected in enrolment boom policy, I searched for a new theoretical lens to explain the historical and geographical variations in female participation in computing. I found Anne Witz's closure theory to be a good fit: the history of how computing masculinized in the 1950s-70s is is well explained by closure theory, as is how academic CS masculinized in the late 1980s. Anne Witz's concept of dual closure — where oppressed groups themselves oppress other groups to try and climb the social ladder — also fits with the conflicts observed amongst women in computing. I find that policies and discourses both play critical roles in the closure of computing.

Chapter 6. *Evidence That Computer Science Grades Are Not Bimodal* (ICER 2016) presents two studies linked to the question of whether computer science grades are bimodally distributed. This is a common belief amongst computer science educators. Also commonly believed by CS educators is that some students "have it" and others do not — a discourse that has been linked to excluding women and other marginalized groups from male-dominated fields such as computer science [128, 136, 199]. The use of this exclusionary kind of discourse to exclude minority groups is expected from closure theory.

I was inspired to investigate this after seeing Ahadi and Lister present an argument at ICER 2013 that CS educators' belief in bimodal grades is not only likely to be false, but is linked to the notion that some students "have it" and others do not. I conducted a statistical analysis of 778 final grades distributions of undergraduate CS classes, and found that they were overwhelmingly normally-distributed. With Jesse Berlin, I then ran an experiment on CS professors where we asked them to categorize a series of histograms in terms of what probability distribution a given histogram had come most likely come from. We found that professors who believed more strongly that CS requires an innate ability were also more likely to categorize an ambiguous distribution as bimodal.

1.3 Contributions

As noted earlier, I started this thesis with the goal of answering the question of why the percentage of women in computer science in the US and Canada has not improved in the past decade despite the substantial effort put into improving female representation. In retrospect, it was naïve to think I could answer this question in a single PhD thesis — it is a large and wicked question. I have, however made progress toward an answer.

The chapters in my thesis make a number of contributions toward an answer:

Chapter 2 contributes a conceptual framework where I conceive of interventions in terms of the leverage they have in a system and who they target. Many existing efforts such as women's lunches are low-leverage, and are unlikely to change the system.

Chapter 3 identifies the boom-and-bust cycle in CS undergrad enrolment as significant for explaining the falling percentage of women, differentiating CS from other STEM disciplines. The percentage of women dropped during each of the booms, without any recovery between the booms.

Chapter 4 finds that in the current enrolment boom, policy makers are not considering that the policies they implement could affect gender diversity.

Chapter 5 identifies Neo-Weberian closure theory as a useful lens for explaining the historical trends of female representation in computing both in industry and academia. It also extends and applies Witz's closure theory to an educational (rather than specifically occupational) setting.

Chapter 6 provides evidence that a common discourse in CS education (CS grades are "bimodal") is not only false, but linked to another discourse already identified in the literature as hegemonic ("The Geek Gene", "brilliance"). This kind of discourse is a common tactic used in exclusionary occupational closure.

Some of my other contributions span multiple chapters. In chapters 3 and 5, I develop the notion of "generations" of women in computing, and examine how the different generations of women have had different and conflicting goals in terms of gender equality.

Throughout this thesis, I find it useful to think about the policies used in addressing gender diversity. This is a conceptually different lens from the usual literature in CS education, which tends to leave policies in the background or outside the frame of analysis.

Indeed, the story of my thesis represents a change of thinking from the psychological — the standard in CS education — to the critical sociological. Perhaps the largest lesson I learned in this thesis was the value of a critical theoretic sociological lens, and particularly social theory, in understanding gender dynamics in computing. Sociology is seldom used in the ICER community [134], and one of the contributions across my papers is to start to connect the CS education literature to more sociological literature.

A contribution I will focus on is my use of closure theory to provide a theoretical understanding of why computing is gendered. I find that closure theory can explain both the historical and geographical variations in female representation in computing. In doing so I bring together the literature on the history of computing, science and technology studies (STS) and CS education. My theoretical model is based on Anne Witz's closure theory and is introduced in chapter 5 and summarized in chapter 7.

Using closure theory provides an explanation not only for why computing is gendered, but also why changing this has proven so difficult. Policies and discourses are responsible for gendering computing, but a dearth of initiatives target these underlying factors. It isn't just that we lack initiatives which are high-leverage: we lack initiatives which target the root cause of social closure.

A wicked problem, like how to open computer science to more women, is the sort of problem that can seem intractable, or unclear where to start. My experience in talking to CS professors is that many genuinely want to change, but do not know how to effectively go about it. In my thesis I identify policies and discourses that can be feasibly changed by computer science professors, such as admissions policies and the bimodal grades discourse.

We have a tendency in the CS education research community to focus only on individuals, leaving the social systems to the background or not even in the picture. Throughout my thesis I have produced examples for the CS education research community that use lenses which focus on the social forces rather than the individuals. It is my hope the papers in this dissertation will be followed by many more sociological CS education research papers.

Chapter 2

Leverage Points: Are Diversity Initiatives Changing The System?

When I first started asking why the diversity initiatives in computing were not having more of an apparent effect, I turned to the lens that is most accessible to computing education researchers: psychology. At the time, stereotype threat and social psychological interventions were getting a great deal of press. This paper [157] reflects a transition in my thinking about my central question in terms of psychology to thinking about it structurally.

2.1 Psychological Thinking

At the beginning of my PhD, I wondered if the diversity initiatives themselves might be having counterproductive effects. Could attending an event for women in computing trigger stereotype threat in women, or have demotivating effects? For example, Betz and Sekaquaptewa found that feminine science role models demotivate young girls, who believe that being both feminine and a scientist is an unattainable goal for them [22]. Chestnut and Markman found that stating that "girls are as good as boys at math" actually reinforces beliefs that girls are worse at math — since it begs the question of why you would need to mention this [42]. Brown et al. found that telling women they had been selected for a mathematical leadership position based on their gender triggered stereotype threat [28]. And Kaiser et al. found that victims of workplace sexual discrimination are less likely to be believed if their employer has some token diversity structure (e.g. diversity training) in place [118].

I started thinking about diversity initiatives in terms of "implicit" and "explicit" interventions, where implicit ones do not advertise themselves as diversity initiatives and hence have less potential to trigger stereotype threat. When presenting this typology, I was asked where one-on-one interventions would fit into this scheme.

When I encountered the Universal Selective Indicated (USI) model of categorizing public health initiatives, I immediately noticed a parallel between the Universal category and my implicit category, and the Selective category and my explicit category. The Indicated category matched up to those one-on-one interventions I hadn't been able to categorize.

Retrospectively looking at this paper, I realize that I was not critical enough of the Universal initiatives. One of the papers that had motivated me to see Universal as best was Yeager and Walton's review of social psychological interventions [222], in which they argue that "stealthy" interventions are best. However, some of the papers described by Yeager and Walton have not stood up to replication [59, 223]. And if the goal is system change, it is questionable how desirable a low-leverage Universal initiative would be compared to a higher-leverage Selective intervention.

2.2 Systems Thinking

At the same time as pondering the psychological effects of initiatives, I was also learning about systems thinking for the first time. When learning about leverage points I was struck that most of the diversity initiatives I had encountered were low-leverage. Women in computing lunches, for example, are not system-changing. They provide a band-aid but are unlikely to lead to changes in power structures in computing.

When writing the paper I had not yet encountered the work of Rosabeth Moss Kanter [119] and so did not have the concept of tokenism available to me in describing low-leverage change. In retrospect, bringing in the literature on tokenism would have made for a stronger paper when talking about low-leverage Selective change.

While my paper includes a psychological lens, you can see my structural thinking starting to take hold around the very concept of the paper: looking at initiatives as the unit of analysis. Literature on women in computing generally only considers individuals (e.g. women, students, educators) as the unit of analysis. While there is policy-focused literature within the realm of CS education (e.g. [89, 207, 8, 48, 14, 12]), it is rare to see policy-focused work at ICER (e.g. [99]). As of the time of writing this thesis, this paper is still the only ICER paper which considers policies/initiatives as a unit of analysis.

2.3 Background: The Cases of Women in Computing at Harvey Mudd College and Carnegie Mellon University

In writing this paper, I assumed my audience was familiar with the gender diversity efforts at Harvey Mudd College and Carnegie Mellon University, as these efforts are well known within the CS education community. Since I make this assumption again in subsequent papers, in this section I provide some background for the reader.

2.3.1 Unlocking the Clubhouse

This 2003 book by Jane Margolis and Allan Fisher mostly focuses on the experiences of women studying computer science at Carnegie Mellon University (CMU), and is the result of a longitudinal study of female and male students there. The book is highly qualitative, and takes a constructivist approach to research. While the book is not explicitly feminist, cultural feminist Carol Gilligan is cited a number of times throughout the book[1].

The first two chapters detail how, from a very early age, computers are gendered objects: they are "boys' toys" and boys are given more access and encouragement to learn how they work. When girls do use computers, they are taught to interact with them as passive users, rather than active controllers of

[1] Gilligan is known for her work characterizing "female" ethics in contrast to "male" ethics; cultural feminism has been widely criticized for essentializing gender roles, as discussed in .

how the computer functions. In school, the computer labs are seen as boys' spaces where girls are not allowed. IT curricula in K-12 are designed around boys' interests (e.g., video games) rather than girls' interests (e.g., nurturing, an area where Gilligan is cited).

The third chapter focuses on why the women and men in their study had chosen to study computer science. There are few differences: both groups enjoy the puzzle solving and creative aspects of computer science. While the desire to study CS in order to help others is more common amongst women, Margolis and Fisher note that it is not a categorical difference between the genders.

The next few chapters discuss the experiences of female and male students once they do start their computer science educations. Margolis and Fisher detail the construction of "geek culture" at CMU and the initiation rites of students into this culture — and how it turns off many women and some men. Margolis and Fisher discuss the "erosion of confidence"[136] of the female students in a culture where they are made to feel where they have less experience and aptitude than their peers.

In discussing which women persist in the CS major, they note it is mostly the women who "have always been around computers" who tend to stay. Other "persisters" that are more counter-intuitive are the women of colour, particularly from developing nations, who were motivated by financial opportunity. For both groups of "persisters," having a belief that hard work, rather than a "geek gene", was necessary to succeed, was important for the women who persisted in the CS major, as was having a support network.

Chapter 8 is the last chapter, and describes the interventions made at CMU and how they were created in response to the data described in the rest of the book. Five major changes were made at CMU which Margolis and Fisher describe as successful:

1. CMU created four different entry points into the CS major. Courses for inexperienced students have more breadth, context, and social applications. The courses for inexperienced students made it more possible for students without experience to catch up.

2. CMU's admissions requirements were changed to a "focus on non-numerics." Combined with the new entry points in to the major, students with no CS experience could now more easily enter the major.

3. CMU attempted to improve their teaching. Top professors were assigned to teach the CS1s, and training for TAs was increased, including adding diversity training.

4. Relatedly, CS faculty were asked to reflect on how they may promote the "hacker culture" when teaching and how to mitigate this. Faculty were asked to instead talk about their research in class.

5. CMU created a high school outreach programme.

Margolis and Fisher also reported on "seemingly unsuccessful changes":

1. Targeted letters to female applicants to the CS programme.

2. Having female faculty phone female applicants to tell them about the CS programme.

3. A women-in-CS club.

As a result of their successful changes, the percentage of women at CMU increased from 7% to 40%, from 1995 to 2000. They present this fact as proof that their interventions were effective, but did not collect any data on which interventions were most effective and how. Reading only the book gives one the impression that the categorization of "successful interventions" versus "apparently unsuccessful" is based on anecdotal experience.

The book concludes with lessons for other universities and what was necessary to make these changes work at CMU. They found it was necessary to have a champion who led these efforts, a body of faculty who were willing to go along with it, and the willingness and ability to tailor changes to the local environment. Again, it is worth noting that these changes were made based on an extensive study of the experiences of their students.

A paradigmatic weakness of the book is that Margolis and Fisher failed to really evaluate the interventions that they implemented. This a common weakness in the women-in-CS literature [47]; much of this chapter feels like a so-called "Star Trek paper" as they "they boldly went where no man had gone before". It is not clear which of their changes were most important.

Blum and Frieze conducted follow-up work to Margolis and Fisher [25], finding that the whole student culture *has* been changed there. Blum and Frieze's work, however, does not evaluate *the interventions* but rather examines the culture after the holistic changes were made.

Blum and Frieze found that the culture has become more inclusive, and that stereotypes and "nerd culture" were less salient. Interestingly, they claim that it is important to have a women-in-CS club, which Margolis and Fisher had described as having had no or little effect. Between the two studies we see positive effects from changing the admissions requirements, having multiple entry points to the major, and not having faculty reinforce the "hacker culture" in class.

In my paper I describe having a women-in-CS club as low-leverage. It is worth noting that the Women@SCS group has made more than low-leverage change at CMU. The group has become influential in the school, and a major source of student life [76].

2.3.2 The Harvey Mudd Story

Over the course of seven years at Harvey Mudd College (HMC), systemic changes in their CS programme resulted in the fraction of women in their CS major increasing from 12% to 40%. The efforts at HMC to increase female participation in undergraduate CS have been written about in multiple papers [6, 120, 5]. Alvarado et al.'s 2012 "Increasing Women's Participation in Computing at Harvey Mudd College" as I find it the most comprehensive of those papers, and provides more recent data than their earlier work.

The efforts at HMC have had a high profile in the CS education community. While CMU was the first reported case of a university to make similar, successful changes, HMC was the first university to quantitatively evaluate their interventions. The positivist approach of Alvarado et al. has a much greater appeal to the positivistic CS education community, and has been generally regarded as the gold standard ever since.

Unlike at CMU where Margolis and Fisher first studied their students and made changes to their programme based on their findings, Alvarado et al. went straight to change-making and enacted three sets of changes to their CS programme. No discussion is made in their work of where they got their change-making ideas or why they chose particular changes over others.

The first set of changes was to the introductory course sequence. Like at CMU, they created three different CS1s: one for experienced students, one for biology students, and one for everybody else. All three CS1s provide a contextualized, breadth-first curriculum that is highly modular in its content. In designing these CS1s, Alvarado et al. found it important to:

1. Ensure students can write interesting programs on day one.
2. Level the playing field for inexperienced students.
3. Chunk up the curriculum into independent modules.
4. Order the material carefully.
5. Go "from practice to theory to practice" in the curriculum.

The second set of changes that Alvarado et al. implemented was to increase undergraduate research opportunities for first-year students. Initially this was only focused toward first-year women; later, this was broadened to all students.

The final set of changes was to send the first-year women in CS1 to the Grace Hopper Celebration of Women in Computing (GHC). GHC is a conference for women in CS which involves women presenting their research, career workshops, and networking events. Alvarado et al. found that early timing mattered in the recruitment, and that before the trip, students should be primed about what an academic conference is like.

Alvarado et al. surveyed students currently in the programme as well as recent alumni to examine which factors were important in their choice of CS as a major. They found that: CS1 was important to 80% of the men and women; research opportunities were important to around 65% of women and 25% of men; and GHC was important to 45% of women.

Alvarado et al.'s evaluation of the changes at HMC is subject to a number of limitations inherent to their survey methods. Alvarado et al.'s survey only covers the topics about which they thought to ask. The results are subject to biases in the participants' memories, and as with all surveys, are subject to what the participants are aware of in their decision-making processes. Alvarado et al. cluster the whole CS1 experience into one survey item, and do not evaluate their smaller claims about how to design a CS1 (e.g., ordering material, write programs on day one).

Furthermore, the reductionist approach to evaluating the different initiatives in isolation ignores the effects of combining the three sets of changes.

The sampling is also concerning: Alvarado et al. only administered the survey to CS students and graduates. As such, the survey is subject to survivorship bias. Their analysis of their results would be stronger if they had also surveyed non-CS students for comparison.

Furthermore, the reporting of the survey results in this particular paper is a bit misleading. Looking at Alvarado et al.'s earlier work [5], we see that they surveyed about more than just the three sets of changes. For example, when it came to choosing to major in CS, "Interactions with CS professors" was almost as important to women as the CS1 experience. This particular paper, however, only reports the survey results pertinent to the three sets of changes; the other factors students found important are not present for comparison. It's worth noting that for female participants, going to Grace Hopper was the *lowest-rated* of the surveyed factors.

I am critical of the importance of sending students to Grace Hopper, particularly as it was the lowest rated factor in the survey. Why send female students to Grace Hopper and not a conference such as SIGCSE or CHI? Alvarado et al. argue that seeing real research is part of the importance of the GHC experience, but this is not unique to GHC. The practice of only sending women to GHC also means that women are singled out for "extra help," which could potentially trigger stereotype threat [28] and decrease self-efficacy[106, 201].

A strength of the paper is that Alvarado et al. report on teaching their CS1s at two other universities (Bucknell University and UC Riverside). However, they do not provide evidence that their CS1s improved the gender ratios at either institution. Instead, there are only anecdotes of increased satisfaction. It is worth noting that they had mixed results at UC Riverside, where they did not split students by experience level. In Maria Klawe's account of the changes at HMC, she boasts that "other institutions can easily replicate"[120] HMC's successes in attracting women into CS. I find this overly optimistic, as it ignores the cultural factors at HMC which made these changes possible, such as how Maria Klawe mandated that all HMC students take a CS course. Klawe gives CMU and UBC as other examples of success, but again ignores cultural factors there, such as having faculty and administrators who are interested in diversity issues.

Scaling up Women in Computing Initiatives: What Can We Learn from a Public Policy Perspective?

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ABSTRACT

How to increase diversity in computer science is an important open question in CS education. A number of best practices have been suggested based on case studies; however, for scaling these efforts up in a sustainable fashion, it remains unclear which types of initiatives are most effective in which contexts. We examine gender diversity initiatives in CS education from a policy analysis perspective, adapting McDonnell and Elmore's 1987 notion of policy instruments, wherein the initiative is the unit of analysis. We present a conceptual framework for categorizing the different policy instruments by a cross of 'leverage' and 'targetedness', and discuss how different types of initiatives will scale. We argue that universally-targeted, high-leverage initiatives are most important for scaling up diversity initiatives in CS education, with medium-leverage change being a stepping stone to high leverage change.

1. INTRODUCTION

In the past three decades, a great deal of effort has been put into trying to improve female participation in computer science. Yet, the numbers in North America haven't budged: women continue to make up only 18% of CS majors [21].

Some efforts have had tremendous, sustained results. For example, Carnegie Mellon and Harvey Mudd have both increased the percentage of women studying CS from around 15% to around 40% in the span of a few years [1, 38].

These initiatives remain unusual, however. While they provide proof that change can happen, they do not provide a roadmap on how to bring that change to scale.

Scale has become a new focus for CS education [28, 20]: as CS is increasingly taught to a wider audience – especially in k-12 school systems – how can we handle the scale? To look at the issue of scale, we adopt the lens of public policy analysis: we consider women-in-computing initiatives as acts of policy.

Researchers who study education at scale – particularly education policy – often work with units of analysis such as initiatives, policies, schools, or regions. In comparison, in the CS education community we tend to work with individuals as our units of analysis. Even when we evaluate initiatives, we tend to evaluate one initiative at a time, using the beneficiaries of the initiative as the unit of analysis.

In this paper we will be considering initiatives as the unit of analysis, rather than individuals. We present a conceptual framework for classifying diversity initiatives, providing a first step toward a policy analysis approach to computer science education.

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2. POLICY INSTRUMENTS

In this paper we treat women-in-computing initiatives as acts of department or classroom policy. This framing of diversity initiatives allows us to draw on literature from public policy analysis. To simplify the scope of this paper, when we talk about 'diversity' we will focus on gender diversity specifically. We will return to the broader diversity issues in subsection 7.1.

We use a broad definition of 'initiative': any formal effort to increase female engagement in computing. Some examples of what we mean by initiative, or policy, include:

Admissions criteria change: changing admissions criteria to focus on 'non-numerics' like at CMU [38]

Degree requirement change: having multiple CS1s separated by experience level / applications [1]

Curriculum change: using MediaComputation to teach CS1 in a context-focused fashion [26]

Pedagogy change: randomly calling on students to ensure that all students speak equally in the classroom and overcome a 'defensive climate' [24]

Sending students to the Grace Hopper Celebration: to foster community amongst female students and expose them to the 'real world' of computer science [1]

Research opportunities for first-years: to foster early interest in CS [1]

K-12 outreach: bringing k-12 students to the university to expose them to computer science activities, such as via a summer camp or day-camp [14]

The education policy literature provides us a notion of 'policy instrument': thinking about qualities of policies themselves, using the policies as units of analysis. The approach comes from McDonnell and Elmore's 1987 classification of macro-level policies as being mandates, initiatives, system change, or capacity-building [40].

Other policy researchers have classified policies differently (e.g. [18]); the insight here is that policies themselves can be classified and their classifications theorized upon.

As our focus here is on department-level policies – rather than nation/state-level – with a focus on scaling up women-in-computing initiatives, we have constructed our own conceptual framework of policy instruments. We classify women-in-computing initiatives by two axes: 'targetedness' (how broad the audience is) and 'leverage' (how deeply the system is changed).

3. TARGETEDNESS

In public health, the Universal/Selective/Indicated (USI) model has proven to be an effective conceptual tool for forming public health initiatives [51]. In this model, initiatives are categorized by the intended audience: universal strategies are aimed at whole populations; selective strategies are aimed toward at-risk groups; and indicated strategies are aimed toward individuals displaying signs of the condition in question.

To give some more concrete examples from suicide prevention:

Universal initiatives: restricting exposure to suicide content in mass media, adding barriers on bridges, and restrictions on pharmaceutical dispensing [17]

Selective initiatives: selective initiatives here include suicide prevention centres and hot-lines, community or school suicide prevention programmes, and programmes for veterans and military personnel [17]

Indicated initiatives: training general practitioners to spot warning signs in patients and how to talk to patients about suicide, postvention, and crisis hot-lines [17]

Here we'll extend the USI model from public health to an education setting. We will refer to the spectrum it represents as 'targetedness': with universal initiatives being less 'targeted' and indicated ones being most 'targeted'. 'Targetedness' refers to how *wide* the audience is, not which audience is being targeted.

3.1 Universal initiatives

In an education context, our idea of "population" differs. A "population" can be a whole classroom of students, a whole CS department or school – or even the general population of a country. The key notion is that universal initiatives are carried out without regard to population target groups or risk factors. Examples of diversity initiatives in CS education which are universal include:

- A CS department makes a mentorship programme available to all students
- Pair-programming and peer instruction for a whole classroom
- A university mandates that all students need to take CS, and its CS department provides multiple, engaging, versions of CS1 that are tailored to different students' interests – like at HMC
- A department changes their admission process that affects all CS students – like at CMU
- A conference switches to using blind review of its submissions.
- A CS professor implements a 'social-psychological intervention' in their classroom (e.g. values-affirming essay), to improve the self-efficacy of all students [53]

Each of these initiatives affects a differently sized population, but the initiative affects all members of its population. It is worth noting that all of the above practices are known (or thought to) to improve female representation in CS. They disproportionately benefit women and other minorities, but also aid majority-members. The same is true of the universal initiatives for suicide prevention: restricting suicide content in the mass media affects all mass media consumers, but disproportionately helps those with suicidal ideations.

While it may seem quite costly to run a universal initiative, given that it has to reach the whole population, recent meta-reviews in public health have found universal initiatives are actually the most cost-effective: "a large number of people at small risk may give rise to more cases of disease than a small number who are at high risk" [17]. And as many diseases are contagious, universal initiatives can improve the resilience of the whole population.

Furthermore, as universal initiatives target the whole population, they provide a means of reaching at-risk individuals who are not in contact with institutional services [17].

3.2 Selective initiatives

In comparison, selective initiatives target a population known to be underrepresented in CS; they specifically and explicitly benefit that group, and provide them with targeted support to 'level the playing field' with dominant groups in CS. Examples include:

- A CS department makes a mentorship programme available to all female students
- Departmental women-in-CS clubs
- Giving the opportunity for female students to go to the Grace Hopper Celebration
- Outreach initiatives for school-age girls
- Scholarships for women in CS

Many selective initiatives in public health – suicide-related or otherwise – have been found effective. Meta-reviews have noted that long-term selective initiatives tend to be more successful than short-term ones. Selective initiatives need to be culturally and contextually appropriate to the audience(s) in order to be effective [17].

Certain selective initiatives have been noted as having potential harm – for example, being seen associated with a group for a stigmatized disease/condition. Like in public health, stigmatization has the potential to be an issue in education. Audit studies have found that job candidates associated with affirmative action (which targets specific groups) are perceived as less competent than identical job candidates without those associations [31]. This effect is strongest when the job candidate's competence is ambiguous [31]. Some qualitative studies of women in science have also noted that beneficiaries of research grants for women in physics feel they are perceived as less competent for receiving the "women's award" rather than a traditional research grant [48].

3.3 Indicated initiatives

Finally, some examples of indicated initiatives in CS education would include:

- A CS department makes a mentorship programme available to students who have been flagged as struggling in their studies
- A teacher takes the time to encourage a student to study more CS
- An academic adviser notices a student is lacking motivation to study CS, and takes the student to Grace Hopper with them
- A supervisor notices a student is facing sexual harassment in their research lab, and makes appropriate steps to protect the student

The effect of indicated initiatives can be quite strong for the individuals it affects: one-on-one encouragement is a strong indicator of whether black students will take CS [42, 55, 28]; it is strongly beneficial to women also [42].

Indicated initiatives, however, rely on educators to be able to recognize students who need help, and be able to effectively help them. For us to rely on indicated initiatives requires all (or nearly all) CS educators to take part – and as a result scales poorly.

4. LEVERAGE

In contemplating scaling up changes, it is also worth considering whether the changes are system-changing or are relatively superficial. Systems thinking offers the notion of *leverage points*: places and ways one can change a system. Donella Meadows constructed a categorization scheme of types of leverage points, and organized them by how much leverage they have in a system. The list in this section goes from least leverage to most – in other words, how deeply (and effectively) the system is changed.

Jay Forrester, a pioneer of systems thinking, noted that although people in a system often know intuitively where to find leverage points, "more often than not they push the change in the wrong direction" [41]. For example, in one of Forrester's studies of urban dynamics from the 1960s, he found that subsidized low-income housing is a leverage point. However, Forrester's model counterintuitively found that the *less* low-income housing there was in a city, the better off the city was – including the low-income citizens [22]. Many more examples of unintuitive leverage-points can be found in [41].

Thinking about leverage points gives us a tool for identifying when changes could be superficial – so that we can focus resources on deeper changes. It also allows to better understand and describe system changes.

It's worth noting upfront that high-leverage changes are often the hardest to make. Systems are resilient and can resist the change; too much change too suddenly can quickly be undone. On the other end, the categories with least leverage – "constants, parameters, numbers" and "the sizes of buffers" – are often superficial. While easier to alter, they rarely lead to systemic change.

4.1 Meadows' Leverage Points

Constants, parameters, numbers: In systems thinking, systems are thought of as having *stocks* (quantities of things) and *flows* (the altering of stocks). A simple example is a bathtub: there is a flow of water from the faucet into the bathtub, a stock of water in the bathtub, and a flow of water out the drain. Changing the rate of flow in and out of the bathtub has an effect on the system – but does not change the fundamental structure of the system.

Meadows notes that much of politics focuses on this leverage point: how much we spent on x, the value of the minimum wage, the value of a tax rate, etc. However, changing the parameter rarely changes the behaviour of the entire system [41]. At the same time, humans tend to focus on parameters [41]; they are concrete and easy to identify.

Sizes of buffers: Some systems have *buffers*: stabilizing stocks that are large relative to their flows. Buffers play an important role in many systems – for example, stores keep inventory rather than ordering new stock every time a customer buys something new. The inventory gives the store a buffer from any delays in deliveries or sudden increases in sales.

The structure of stocks and flows: The structure of how stocks and flows can have an enormous impact on a system [41]. Redesigning a plumbing system, or refactoring a code base, can have large effects.

The delays in the system: Delays in a system affect feedback loops, and can cause unpredictable behaviour in a system. Reducing or increasing delays in the system can have large effects. Often, delays cannot be changed: it takes a fixed amount of time for a baby to mature or for electrons to travel a given distance.

The strength of negative feedback loops: A thermostat is a classic example of a system controlled by a negative feedback loop: if it gets too cold, the furnace turns on. If it gets too hot, the furnace turns off. The result is a room with a temperature which varies slightly around a set equilibrium; any disturbance in the equilibrium and it is programmed to return to that state.

The strength of a negative feedback loop is important relative to the impact it is designed to correct [41]. A thermostat may work well on a cold winter day – until somebody opens a window, decreasing the strength of the negative feedback loop.

The gain of positive feedback loops: Positive feedback loops are self-reinforcing – such as how the more people catch the flu, the more it spreads; or how the more money you have in the bonk, the more interest you earn. Positive feedback loops can also be known as 'success to the successful': for example, the more research grants a professor receives, the easier it is for them to receive subsequent grants.

The structure of information flows: A famous case in energy usage behaviour comes from the Netherlands in the 70s: in a particular suburb of Amsterdam, some otherwise identical houses were built with their electric meters in the basement, and some in the front hall. The houses with the meter in the front hall used one third the electricity as the houses with the meter in the basement, where people rarely saw it. Those who saw their meter every day were hence more conscious of their electricity usage – and used less [41].

Adding a flow of information to the system adds a new loop to the system: it is not increasing the strength of an existing one or its parameters [41]. Removing an information flow is a similarly high leverage change: censorship can have drastic impacts on social systems.

The rules of the system: Even more fundamental than the stocks and flows in a system are the rules which govern it: incentives, punishments, constraints, laws, etc. The rules of a system determine its scope and boundaries. Changing a constitution of a country or an organization is an example of this leverage point.

The power of self-organization: The system's ability to change its own rules and structures is known as *self-organization*. In a biological context, evolution is an example of self-organization. In a political context, social movements provide a different example.

The goals of the system: One of the most fundamental things about a system is its purpose: a school has a goal of teaching students, a hospital of healing patients, a corporation of making profits. If a university changes its purpose from teaching students to producing research – or to making profits – then lower leverage points will be influenced towards that goal.

The paradigm of the system: The shared ideas of those in a system – the great unstated assumptions – make up that system's paradigm[1]. Goals are articulated and made within paradigms. People involved in self-organization act in ways affected by their paradigms. And so, the deepest way to change a system is to change the paradigms affecting or defining it.

[1]Meadows lists a final leverage point, 'transcending paradigms', which contradicts the notion of a paradigm, and has been omitted as a result. Her argument that we should 'transcend paradigms' in favour of systems thinking is in itself a reflection of her own paradigm.

4.2 Simplifying Meadows: 4 Leverage Groups

To simplify Meadows' leverage-point continuum we group her leverage points into four categories, intentionally borrowing the names from Structure-Behaviour-Function Theory [32]:

Structural change: the constants and parameters, the sizes of the buffers, the structure of the stocks and flows.

System behaviour change: changing the gains and delays of the feedback loops.

Function change: changing how a system is controlled (information flows, rules, self-organization, goals)

Paradigm change: changing the very paradigms (in a Kuhnian sense) upon which the system's control is based.

For women-in-computing initiatives, structural changes would include:

- Having CS1 taught by a woman [5] (a parameter change)
- Using female pronouns in assignment instructions [25] (parameter change)
- The size of the departmental Women in CS support group [38] (buffers)
- Assigning groups based on gender [19] (buffers)
- Provide multiple entry points into a CS major [14] (structure of stocks/flows)
- Build "breaks" into the CS1 curriculum as reported in [1] (structure of stocks/flows)

While all these structural changes surely help, they *on their own* do not make for systemic change in CS programmes and classrooms.

System behaviour changes have higher leverage. When it comes to improving diversity in CS, reducing the effects of "success to the successful" makes a major difference. Some system behaviour changes would include:

- Change when students have access to research opportunities [1] (changing delays)
- In CS1, have students write meaningful programs from day one [1] (changing delays)
- Use blind review for scholarship applications [10] (strength of negative feedback loops)
- Reduce and remove potential triggers of stereotype threat, such as posters of Star Trek [13] (strength of negative feedback loops)
- Provide community service learning and co-op opportunities to undergraduates [14] (gain of positive feedback loops)
- Provide more individual encouragement and mentorship to students [14] (gain of positive feedback loops)

Changing how the system is controlled ("function") goes even further in terms of leverage; some examples include:

- Outreach efforts designed to increase/add information flows [14] (information flows)
- More feedback for students (information flows)
- Change entry requirements to the CS major to focus more on 'non-numerics' rather than prior experience [38] (rules)
- Establish a new classroom rule to call on all students randomly, to overcome a 'defensive climate' [24] (rules)
- Perform action research with women and underrepresented minorities in your department [38] (self-organization)
- Empower students to direct some or all of the course content, or use open-ended projects [8] (self-organization)
- Change the goal of the programme to provide an inclusive, positive learning environment for all students [8] (goals)
- Change the learning goals of the class to focus on problem-solving and applications (e.g. MediaComputation [26]) (goals)

And the final leverage point would be paradigm change – some relevant ones would be:

- Shift in thinking: it's the institution that has the problems, not the minority groups [48] (paradigm)
- Shift to an approach to teaching which empowers students, rather than the 'banking model' of education when we deposit 'coins' of knowledge into our students 'bank accounts' [23] (paradigm)
- Shift in thinking: seeing the excellence in computing as something which can be taught/learnt rather than seeing excellence in computing as tied to innate ability (or 'geek genes') [27, 35] (paradigm)

Paradigm changes are difficult to carry out, given the broad change needed to accompany them. When it comes to making change in a system, jumping straight to a paradigm change is usually impractical.

5. TARGETEDNESS AND LEVERAGE

The 'targetedness' and 'leverage' qualities of a diversity initiative are independent; in Table 1 we show some examples of initiatives with varying levels of targetedness/leverage.

For example, the table shows different ways an instructor can provide an indicated intervention with a student: giving a student a buffer from a hostile culture is lower leverage (structure); encouragement affects feedback loops and hence provides more leverage (behaviour); providing information on different study and career goals has more leverage (function); and changing their mindset (paradigm) would be a high leverage change.

A particular leverage point can also vary by targetedness: a CS department launching a mentorship programme could open it to all students (universal), open it only to female students (selective), or have it private to students who have been flagged by faculty as needing extra help (indicated).

On the ground, educators spend a great deal of time on indicated initiatives: working with individual students, wondering what to say to them and how to nurture positive growth. Psychology papers often enjoy a lot of attention amongst educators: they focus on these individual changes. As CS educators, when it comes to diversity, we like to talk about issues such as mindset [47], identity [44], stereotype threat [13] and self-efficacy [7]. When we talk about groups, we still talk about the individuals; e.g. "women are more likely to have low-self efficacy". Although these discuss groups, the unit of analysis remains the individual.

While indicated initiatives call for a background in psychology, universal initiatives more often call for a background in sociology. Effective universal initiatives call for thinking about the 'population' in question as a whole, rather than a collection of individuals.

The CS education literature has an understandable tendency to draw upon more disciplinary approaches from psychology than sociology. In Malmi et al's recent survey of theoretical bases of CS education literature, sociology was not even common enough to warrant a category in their data [36]. Often when we talk about universal/selective initiatives we still do so in the language of psychology – increases to self-efficacy of the individuals in a population [7], reducing stereotype threat of the individuals in a group [13], etc.

	Universal	*Selective*	*Indicated*
Structure	Whether to use female pronouns in assignment instructions	The size of a women-in-CS club	Add a female student you know is struggling to the women-in-CS club's mailing list
Behaviour	A CS department provides a mentorship programme for all CS undergraduates	A women-in-CS club provides a mentorship programme	Provide specific encouragement to a student you know has been discouraged by their peers
Function	Change the learning goals of introductory CS to focus on problem-solving and applications	Change your department's decision making process so a women-in-CS committee provides input on department policies	Counsel a student you know is not engaged with CS about new career goals they can have within the field
Paradigm	Change the goal of your CS major to promote a collaborative, participatory learning environment	Change the paradigm of a Women in CS club to be intersectional and trans-inclusive	Change a struggling student's mindset from a fixed one to a growth mindset

Table 1: Examples of how different initiatives can vary by both targetedness and leverage.

When we look at cases like HMC [1] and CMU [38], they describe their successes as a series of smaller initiatives, typically with medium or low leverage. To a systems thinker, those smaller initiatives are secondary to the high-leverage changes in organizational goals/paradigms. HMC and CMU both made holistic changes to their CS programmes with the goal of increasing diversity, and making this part of how they teach CS. While not acknowledged in their work, the interaction effects of all their changes is likely greater than the sum of each individual initiative: the changes reinforce each other and change the cultures at those institutions.

6. SCALING UP

6.1 Targetedness and Scale

When it comes to scaling up, indicated initiatives do poorly: they require nearly every educator to be ready to help a struggling student one-on-one. This requires both buy-in from educators *and* a time commitment from them: some educators may want to help struggling students but not feel they have the resources to do so. Indicated initiatives also suffer from variability: different educators will vary in their ability to diagnose and help different students.

Selective initiatives at first glance look promising for scaling up. Selective initiatives often seem like an obvious choice and follow a clear logic: a group (such as women) is not studying CS, so we should help them. There is a directness to selective initiatives, and it looks good (optics) to those running it.

6.1.1 Optics

Selective initiatives win when it comes to optics: a CS department can tout their 'commitment to diversity' by showing off their selective initiatives. Selective initiatives often *look* more like an intended group is being helped than universal initiatives – and meanwhile indicated initiatives are usually invisible to the public.

The optics of selective initiatives can be both a blessing and a curse. The upside is that it can be easier to rally resources and political support to help a disadvantaged group directly – indeed, it's often easier to do so than to change the whole system around their needs. 'Band-aid' solutions are common in policy for good reason: everybody wants to help, but only so much. The downside is that ineffective selective initiatives can act as "pink-washing": superficial efforts used to make people/organizations look good, in turn draining resources from other initiatives and impeding higher leverage change.

6.1.2 Illusion of Fairness

Companies which are described as having selective and indicated initiatives are perceived by the public as being fairer companies and better places to work [33].

Problematically, these initiatives can cause an 'illusion of fairness'. In six studies by Kaiser et al [33], participants were grouped in a 2x2 design. Half of the participants were shown information on a fictional company described as having some selective initiative; the other half were given information on a company without any mention of diversity. Then half of the participants in each group were shown evidence that the company they had seen was discriminating against some group (women, blacks); the other half were shown evidence that the company was not discriminating. And then all participants were shown an article about a woman or black man who was suing the company for discrimination.

All participants were then asked to evaluate the company with regard to qualities such as procedural fairness. Troublingly, participants who saw that the company had some diversity initiative thought the company was more procedurally fair, regardless of whether they saw a report showing evidence of discrimination at the company.

Participants were less likely to believe the credibility of the discrimination lawsuit if they saw that the company had some selective initiative. And supporting the paper's findings are a number of legal cases that Kaiser et al reported upon: judges in the US deferring to companies in discrimination cases because the company had enacted selective initiatives – *regardless of how effective they were!* [33].

This phenomenon seems most problematic when the selective initiative is low-leverage. In that case, the lack of real change to the system means that women (or other groups) are still going to be discriminated against — but now they may encounter even more bias *because* of the presence of the selective initiative.

6.1.3 Stigma and Stereotypes

Like in public health, there is potential for selective initiatives in CS education to have counter-productive effects for the beneficiaries. Stigma has been reported surrounding receiving women-in-CS 'help': Margolis and Fisher noted a "you're only here because you're a girl" phenomenon [38]. This has been observed in other fields of science: female physics professors who received research grants intended for women found they were taken less seriously as a result and felt a loss of self-efficacy for "needing to get the women's award" rather than a "normal" research grant [48].

Audit studies have found that resumes of women who benefited from initiatives specifically for women are ranked as less competent than identical resumes without the selective initiatives mentioned [31].

Informing women that they have been selective for special positions to do mathematical work *because* they were women was in one psychology study found to trigger stereotype threat [9] – however, if women were told they were selective based on *both* ability and gender, stereotype threat was not triggered [9].

Yet another social psychological phenomenon associated with selective initiatives is 'subtyping'. When women in CS (or another field) are consistently subtyped as "female computer scientists" rather than "computer scientists", rather than change peoples' ideations of what a computer scientist is, it instead creates a new type in peoples' minds: the *female* computer scientist [45, 6]. This subtype, the *female computer scientist*, is not only separate from the notion of a *computer scientist*, but reinforces that a regular *computer scientist* is not female – effectively further masculinizing the stereotype of computer scientists.

The subtyping effect becomes stronger with repeated exposure. The more effort we put into "women-in-CS" efforts, the more we highlight female computer scientists as *female computer scientists* (rather than computer scientists like any other), the stronger the effect. In short: this effect becomes *worse* with scale.

This is not to say that selective initiatives do not have merit. Instead, organizers of these initiatives need to be cautious of their implementation and wary of the potential side-effects. If selective initiatives are to be scaled up, then even more organizers must be counted on to navigate the potential side-effects.

Universal initiatives do much better with regard to the social psychology around them. If *everybody* receives the same initiative, then you're not making one particular minority group's status salient. Issues of stereotype threat, subtyping and stigma disappear.

6.1.4 Who is Selective?

By helping everybody, universal initiatives also avoid the issue of defining who and who does not fall into a selective group. Feminist theorists such as Judith Butler have well established that gender and sex are both social constructs [11]. If you only offer a programme to 'women', then you need to consider who is a 'woman'. Do you include male-to-female transgender individuals? Female-to-male? When in a trans person's transition do they count (or not count) as a 'woman'? What about intersex individuals (those born with biological aspects of both sexes) or individuals who do not have XX or XY chromosomes?

Other underrepresented minorities in CS suffer from similarly ambiguous boundary lines: race is another social construct with poorly defined boundaries [29]. If you offer a programme for black youth, are half-black youth allowed to attend? One quarter? One sixteenth? What about youth who are black but are adopted by white parents? White youth adopted by black parents?

Selective initiatives essentialize the groups they intend to help. Considering the issue of scale, helping only one group (or a set of groups) can be inefficient, given that people hold multiple identities at any given time.

A computer science department which only provides selective initiatives to women will wind up neglecting other underrepresented groups – who may need the help more than some (but not necessarily all) of the women. It is easy for departments to focus resources on visible minorities such as women and racial groups; invisible minorities tend to lose out on the selective initiative identity politics.

Universal diversity initiatives as a result have the potential to save resources. For example, rather than create a women-in-CS mentorship programme, an aboriginal-in-CS mentorship programme, a deaf-in-CS mentorship programme, and a trans-in-CS mentorship programme, a CS department can implement a mentorship programme for all students. Minority-member students can be stealthily matched with minority-member mentors. Not only are the visible minority groups aided, but the invisible minorities – especially those without faculty advocating on their behalf in department decision-making – are aided as well.

6.1.5 Resources Needed

On the note of resources, fiscal slack can be a necessary (but not sufficient) condition for policy innovation [40]. While universal initiatives are typically cheaper than selective initiatives, they often require a greater upfront cost: this can be politically difficult.

Indicated initiatives require low levels of 'governmental capacity'. This is defined as the ability of the initiating level to implement a policy, and the target to meet its requirements [40]. As professors have a great deal of autonomy over their teaching they have high governmental capacity in their own classrooms. On the other side, universal and selective initiatives suffer from the need for greater governmental capacity.

6.2 Leverage and Scale

Unlike targetedness, the amount of leverage an initiative has does not have a direct relationship with scalability. Leverage doesn't directly relate to who or how many people are affected/involved.

Leverage is about having *lasting* change: higher leverage changes are more likely to be sustained over time. The relevant scale here is not scaling over a population, but scaling over time.

Systems are notoriously difficult to change. Policymakers have long noted that enacting a policy doesn't mean it will be implemented as desired ('fidelity') or be sustained as future policies are brought forward [52, 18]. Higher leverage changes are more difficult to enact but they are more likely to stick once made.

Many selective and indicated initiatives are based on the assumption that a group needs special help. This is part of a paradigm that the *problem is the group itself, rather than what the greater system is doing to that group* [8]. This reflects a paradigm well-documented in the women-in-science literature: whether to change the women or to change the system [30].

Low-leverage changes are easy to understand and explain. They're easier from an optics point of view to work on; they provide a concrete change that one can focus on or take credit for. High-leverage changes are harder to pinpoint, especially when the changes are happening. The path to changing a curriculum is more evident than the path to changing a paradigm, and as a result is easier to rally resources around.

Low-leverage changes are also more easily co-opted by agents with other agendas. Sociologists have repeatedly documented cases of "false change": low-leverage change with little effect used to give a false sense that progress is being made, to stave off more radical change [2].

6.2.1 The Goldilocks Zone

Trying to change just a paradigm of a system is a difficult, if not impossible, task. Instead, queer theorists have referred to the need to start by making change by a *Goldilocks process* [16]. This involves starting with medium-leverage changes, then eventually switching to high-leverage changes.

This process is reminiscent of Vygotsky's notion of *Zone of Proximal Development* [50] but on a system-wide scale. You challenge the system with changes which are at the periphery of what is possible[2], and once you have your 'foot in the door' you continue shifting the system towards your goal.

Psychologists have documented that behaviour affects attitudes [43]. If a department starts making some medium-leverage changes, then people may engage more with the need for these changes, and become more inclined towards high-leverage changes.

6.2.2 *Resources Needed*

Making high- and medium- leverage changes to a system requires an understanding of the system. Information can be one of the most vital resources needed for high/medium leverage changes.

Counterintuitively, high-leverage changes can be the cheapest to implement: it costs very little *money* to change a paradigm, but to change your TA-to-student ratio is likely quite expensive. But while high-leverage changes may need fewer fiscal resources, they need much more political capital and governmental capacity. Changing the goals of an organization requires a great deal of political support – and lack of organized opposition.

Institutional context hence becomes vital here: how is formal/informal authority allocated amongst policy actors, and how are decisions made [40]? For example, one CS department could make decisions through committees; another through consensus-building. Consensus-focused departments are vulnerable to having policies blocked by professors who oppose the changes. This makes it harder to pass policies that have opponents – meaning that high-leverage changes are harder to make. But a consensus-focused department where everybody is brought on-board for a high-leverage change means the change is more likely to last.

6.3 Policy Space

The concept of *policy space* refers to the cumulative effects of previous policies, and how they shape the creation and implementation of new policies [4, 40]. Policies do not live independently, and cannot be thought of independently. Policymakers considering new diversity initiatives in their jurisdictions need to consider how new initiatives would fit into existing systems and interact with existing policies.

If a department or a professor has been used to making changes with a certain level of leverage/targetedness, they are more likely to stick to that level of leverage/targetedness [40]; alternative approaches may be too unfamiliar to them.

Research on how education policies are scaled up has documented multiple stages to the process: first demonstrating a proof of concept that the initiative can be implemented at all, then evaluating that it works, then showing it works in several other contexts, *then* scaling it up and refining it [39]. Frequently, context is the most important factor: many well-intentioned policies have 'failed' for neglecting the impact of context [52].

7. DISCUSSION

A couple papers ([15, 12]) have been written asking the question: why are there more women in other STEM fields than CS? Cohoon attributed the difference between biology and CS to the following: biology faculty have more favourable attitudes towards female students, spend more time mentoring students, and feel more of a shared responsibility for student success [15].

Selective initiatives in biology are relatively rare compared to computer science. Instead the biology faculty have goals more focused towards undergraduate teaching, and the greater buy-in toward teaching has resulted in faculty doing more indicated work.

Other work looking at the differences between STEM fields also points to the paradigms in CS teaching as problematic – the collective belief held by CS educators that ability to perform in CS is fixed [27] is attributed to lower diversity [35].

7.1 Diversity

Our paper has focused on gender diversity in CS. It must be noted that many other facets of diversity exist: race, class, disability, sexual orientation, gender expression, etc. Different underrepresented groups in computer science have differing reasons for their underrepresentation – and individuals belonging to multiple minority-groups face interaction-effects from the multiple biases they encounter.

At the same time, many of the reasons non-gender minority groups are underrepresented in CS are the same as women: lack of encouragement [28], lack of prior exposure [37], stereotypes [49], hostile attitudes and biases [42], lack of role models [42], not knowing the 'hidden curriculum' [38], and not being part of the 'old boys' network' [54].

In many ways, the culture in computing discriminates against those who do not fit the stereotype of the white/Asian male 'nerd': even white male 'jocks' have reported feeling out of place in the CS classroom [38].

Gender has received the lion's share of the diversity research in CS education, and as a result we found it most appropriate to focus on it for this paper. Given the large number of women-in-CS initiatives to draw upon in creating our framework. Since we adapted very general frameworks to do so, we believe our framework will appropriately transfer to other diversity initiatives.

7.2 Limitations

Our conceptual framework provides some insights to the properties of different diversity initiatives, but the work we used to put it together has not been without critique. Meadows' approach to systems thinking ignores issues of historicity and power. While we included the concepts of political support/opposition and policy space in our discussion of resources and constraints, these still leave historicity and power in the background of our analysis.

Both the USI model and the leverage points fall into the structuralist approach to sociology, which traditionally ignores or backgrounds issues of historicity and power. Given the importance of power in diversity issues, future work in examining CS education policy may find it useful to foreground historicity/power – some alternate approaches could have been to use the concept of co-construction [18].

We chose a structuralist approach in this paper because it gives directions forward. While poststructural approaches are useful for exposing the reproduction of inequalities in organizations, they can give very little in terms of ideas for what to do about them. Structuralism gives concrete ideas for educators: *let's try a higher-leverage change; how about something selective? etc.*

7.3 Future work

Policy research, especially at scale, has a difficult time of comparing two policies: you can't necessarily scale up both, and you can't scale them both up on the same population. Experimental research becomes infeasible: policies hence need theoretical backing for scaling up, and research on relevant contexts.

Having developed a conceptual framework for classifying diversity initiatives, and presented some preliminary evidence of the importance of high-leverage changes, our next step is to conduct a mapping study of the CS education literature. It appears that much of the literature focuses on

[2]Political theorists refer to the scale of what is possible as the 'Overton window' [46].

the indicated and selective initiatives; universal initiatives appear underrepresented.

Future work is needed to look at the *micropolitics* of how CS departments make decisions on diversity initiatives. Micropolitics refers to the study of politics in organizations [3], and provides valuable insight for why schools and universities favour particular policies over others.

Existing papers on large-scale efforts, such as at HMC [1] and CMU [38], focus on describing the medium- and low-leverage changes that were enacted – rather than the high-leverage points or the context of their institutions. Furthermore, both works fail to describe the micropolitics of their organizations, only providing short and vague messages like “have a champion” for proposed policy changes.

Within the CS education literature, a paradigm of positivism can easily be spotted in papers on diversity. In Maria Klawe’s account of the changes at HMC [34] she boasts that “other institutions can easily replicate” HMC’s successes in attracting women into CS. We find this overly optimistic, as it ignores the cultural factors at HMC which made these changes possible – factors which include a president like Maria Klawe!

Klawe gives CMU and UBC as other examples of success, but again ignores cultural factors there. Most CS departments feature professors who care about diversity – but their resources and constraints may not favour the changes that worked at HMC. Context is a vital part of understanding what made a diversity initiative ‘work’, particularly the relevant existing resources and constraints.

In order for other institutions to understand *how* to make changes like at HMC and CMU, we need research on how policy actors navigate the political waters to enact change. This political knowledge is vital for scaling up.

As CS educators strive to make widespread changes to the demographics of their classrooms, we need to think about how to transfer and scale up the findings from the existing CS education literature – much more can be done to use the tools from education policy analysis in this research area.

7.4 Take-homes

The purpose of McDonnell and Elmore’s paper was not only to reconceputalize policy, but to give conceptual tools to policymakers. They observed that policymakers are often unaware of the range of policy tools available to them, and stick to instruments that have worked for them in the past. McDonnell and Elmore’s paper gives a structured way for policymakers to brainstorm policy approaches that would be in their blind spots [40].

Similar to McDonnell and Elmore, this paper gives CS educators a conceptual framework for thinking through what policy alternatives are available to them. When educators find themselves seeking to improve diversity, they have an activity available to them now: to brainstorm a change for each leverage point, and for each level of targetedness. The activity may uncover ideas that educators would not have otherwise considered.

8. CONCLUSIONS

While low-leverage, indicated initiatives may be the easiest for a CS educator to start with if they want to make a difference, these initiatives are likely the least effective – and least likely to scale well. Selective initiatives, while popular, present numerous challenges for scaling up; universal initiatives provide greater promise for effective policy at scale.

High leverage changes are most effective long-term, but are difficult to make on their own; medium leverage changes (system behaviour and function) fall into a ‘Goldilocks zone’: they provide an effective place to start, to start shifting the system toward high-leverage change. CS educators may want to consider what feedback loops, goals and rules privilege majority-group members in their classrooms and CS programmes – and how their undergraduate programmes can be changed to level the playing field for all students.

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Chapter 3

The Historical Context: Enrolment Booms Are Key Times for Diversity

In this chapter I examine the historical context of the gendering of computing. As I learned more about sociology, I began to appreciate the importance of understanding the history of a phenomenon. In particular, I was motivated to examine the history of women in computing after familiarizing myself with Soft Systems Methodology (SSM) and Marxist sociology. Through writing this paper, I realized that enrolment booms are key times for gender diversity in the history of women in academic computing, which informed my subsequent work (most directly chapter 4).

To operationalize "gendering", I focus on the relative numbers of women to men in computing, rather than absolute numbers; the numbers of people in computing have changed drastically over its history.

The paper was written in 2013 and published at ITiCSE in 2014 [156], and at the time there was little by way of histories of computer science. Janet Abbate's "Recoding Gender" [2] and Mar Hicks' "Programmed Inequality" [109] did not come out until after I had written this paper. Furthermore, I had not yet discovered Susan Sturman's unpublished thesis on women in computing events [193], which includes a chapter on their history. As a result, the paper misses all of these sources — which is why I later rewrote the paper in chapter 5 to include them.

In the hope that others would want to learn from my journey, I was motivated to put both versions of the paper in the thesis. This allows the reader to see my development. While explicitly showing one's development is atypical in academic writing, I have come to believe that only showing the end result does a disservice to new researchers. Because the central contribution of this thesis is theoretical (chapter 7), I believe it is important to demonstrate the provenance of my theorizing.

3.1 Soft Systems Thinking

As I learned more about systems thinking, I was drawn to Soft Systems Methodology (SSM) over traditional "hard" systems thinking. SSM is an alternative to action research: it provides a methodology for approaching complex social situations, understanding the system, and then identifying changes which are both systemically desirable and culturally feasible. For this paper, I saw university computer science departments as my "system."

In SSM, the process of inquiry itself is viewed as a system, and the researcher/observer is considered part of the system they are observing and changing [37]. The actions of the researcher can change the system under observation; the system is not static nor is it separate from the researcher [37]. Checkland et al. developed SSM out of dissatisfaction with traditional systems thinking, particularly its technical/rational understanding of management and structural functionalist view of society [37].

SSM itself has evolved with time. In the early form of SSM, there is a seven-step approach, which begins with expressing the problem situation and understanding its history in order to conceptualize the situation's root causes. The approach is intended to be iterative, with the researcher returning to earlier steps as they proceed.

Since its initial development in the 1970s, SSM has evolved from a very structured set of steps for the researcher to follow and then interpret in a structuralist lens to a very loose set of guidelines for the researcher to approach from a poststructuralist lens [37]. At the time I was writing this paper, I was more comfortable with the structuralist view.

It is worth noting that SSM is not without its criticisms. For example, Jackson has argued that SSM does not handle issues of coercion and power well, and has promoted a critical systems thinking approach instead [114, 113]. While Checkland states that he was influenced by Marx in his work [37], many of Marx's key ideas are not deeply present in his methodology. For example, Checkland tells his readers to examine the history of a given system, yet the models/solutions typically yielded by SSM are surprisingly ahistoric.

I was not familiar with Jackson at the time I wrote this paper, but did see the same need to adapt SSM to a more critical approach. As suggested by SSM, I began with a historical analysis, but ensured my historiography would be both power/resource-focused and feminist in nature.

3.2 Marxist Thinking

A key step of later forms of Soft Systems Methodology is to identify conceptual models to explain the situation/system of interest. Studying the history of women in computer science led me to see conflict theory as an important tool here. Not only does my ITiCSE 2014 paper document gender-based conflict, but I also make a point of documenting the history of conflict amongst the women in computer science.

Marxist conflict theory conceives of conflict between groups as arising over the allocation of resources. These resources can include financial capital — or how to acquire this capital (i.e. access to paid labour). Rossiter's history of women in science describes how women fought for access to scientific jobs and educations.

One of the ways in which Soft Systems Methodology has clearly been influenced by Marxist thought is through the practice of having the SSM researcher begin with history. Historical investigation is a key aspect of Marxist sociology, particularly in looking at the history of social forces (rather than key individuals) with an emphasis on historical specificity.

My paper follows the Marxist tradition: my history is that of the social trends, rather than individuals, with the goal of trying to describe how computing came to be organized at a given time. My historiographic approach was one of the contributions of the paper: at the time, the other histories of women in computing had followed the "great woman" approach to history.

A Historical Examination of the Social Factors Affecting Female Participation in Computing

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ABSTRACT

We present a history of female participation in North American CS, with a focus on the social forces involved. For educators to understand the status quo, and how to change it, we must understand the historical forces that have led us here. We begin with the female "computers" of the 19th century, then cover the rise of computing machines, establishment of CS, and a history of CS education with regard to gender. In our discussion of academic CS, we contemplate academic generations of female computer scientists and describe their differential experiences.

General Terms

Human factors

Keywords

Computer science education, women in CS, studies of CS

1. INTRODUCTION

Increasing the participation of women in computing is well-established as an important and difficult task in the CS education community [36, 15]. Much of why it is hard to increase the participation of women – and other underrepresented groups – is because social structures are complex, dynamic systems. We cannot reduce the matter down to a few issues that, if fixed, would change everything. For example, meta-reviews of diversity initiatives outside CS have found that historical trends must be considered when designing initiatives, since *"the disruption [of the status quo] is usually not complete, nor fully shared by everyone, leaving traces of the old gender order to co-exist with an emerging newer and more complex notion of gender at work.* [8]

This paper presents a historical sociology of female participation in North American computer science. By *historical sociology* we refer to an approach to history which focuses on the social and cultural developments, forces and trends. Existing histories of female participation in CS instead focus on individuals, such as Grace Hopper, Ada Lovelace and the ENIAC Girls (e.g. [25, 17, 40, 2]).

The histories of female computer scientists are fascinating, and useful for presenting examples of female role models in the field. However, a focus on individuals takes away much of the context: what was it like being a computer scientist at that time? What was it like being a woman in society then? Understanding these social trends is important for changing a status quo where women continue to be underrepresented.

Not much has been written about the history of academic CS; most histories of computing focus on the technology, and end in the 70s (e.g. [12, 18]). For young CS educators, there is little detailed post-70s history. Our goal in this paper is to provide background information on what has happened with regard to female enrollments in CS since the 90s – which in turn requires us to look at what led to that point.

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1.1 Background Information

1.1.1 Types of Barriers

As we discuss the barriers faced by women in CS and STEM careers, we find it useful to categorize these barriers into a 2x2 grid:

	Intentional	Unintentional
Institutional	*De jure* discrimination	*De facto* discrimination
Individual	Explicit sexism	Implicit sexism

Institutional vs. Individual. Is it a policy, such as restricting enrollment in CS, or a lack of maternity leave? Or is it the direct behaviour of individuals, such as sexual harassment or a prejudice against women?

Intentional vs. Unintentional. Policies created without considering the effects on women, and subconscious bias against women, are examples of unintentional barriers; sexual harassment and the explicit barring of women from studying CS in some countries are examples of intentional barriers.

2. A PRE-HISTORY OF WOMEN IN CS

2.1 Women as Computers: from the 1820s to the 1940s

2.1.1 19th Century and Early 20th Century

The 19th century marked the rise of women's colleges in the United States [42] as policies barring women from education were loosened. This came hand-in-hand with first-wave feminism, in which women fought *de jure* discriminatory practices in North American society. Women campaigning for access to higher education did so on an argument that it would "produce better wives and mothers". For women of privilege in American society, a basic understanding of science and math in turn became "necessary for motherhood".

It should be emphasized that this was a trend for white women of *privilege* – most women who studied science in the 19th century were the daughters of scientists and other intellectuals. Consider, for example, that Ada Lovelace was a countess in a family of mathematicians [25].

For the women scientists that emerged from these colleges, there were few job opportunities. Teaching at the women's colleges was the main possibility. Working as a "computer" was another possibility [42]. Women pursuing PhDs or faculty positions were expected to be single or "in no danger of marrying"; marriage meant resigning from the programme or their job [42]. As time progressed and society progressed, women in these positions began to feel they could be both wives and scientists – when they resisted the norm of resigning upon marriage, they were met with opposition: they were threatened and usually fired [42].

1870-1900 marked an era of slow infiltration: women began entering doctorate programmes at traditional (male) institutions in countries such as the US and Germany [42]. Most universities were hesitant to allow the women into the PhD programmes, but would instead admit them as "special students" and give them bachelor's degrees instead. Engineering schools, however, remained resistant to women [40, 42]. While by 1910 women were starting a presence in science at traditional institutions, there was no equality in employment, and jobs remained deeply "sex typed".

With the slow rise of women in science came the corresponding rise of "women's work" in science [42]. So-called women's jobs typically were "assistants" to scientists, or working as computers for larger groups. These women were systematically ignored in the larger scientific community, left out of lists of scientists, conferences, and histories [43]. Indeed, from 1911 onward there were overt efforts to reduce the numbers of women in science.

2.1.2 Women's Work

It should be emphasized that computation was considered "women's work" in the 19th and early 20th century. Looking at the history of the social sciences in this time, quantitative methods were considered "low" enough that women could do them – but qualitative methods required "the intellect of a man" [35]. The reversal of the status (and gendering) of quantitative vs. qualitative work in the social and biological sciences happened well into the 20th century (sometime between the 30s-50s) [35].

During the World Wars, women were stereotyped as better programmers: "programming requires lots of patience, persistence and a capacity [for] detail and those are trains that many girls have" [25]. This stereotype persisted into the 40s [17], and even as far as the 60s: a 1967 issue of *Cosmopolitan* featured Grace Hopper describing programming as "*[it's] just like planning a dinner*" [18].

2.1.3 The World Wars

By the 1920s, women in academia were still largely kept to the women's colleges [42]. The colleges, however, provided a place to organize campaigns for change. Women began fighting for access to education, using evidence from psychology and anthropology that women too were capable of science/math [42].

The 20s and 30s marked an expansion of government-employed scientists, who were assigned "women's work" (assistants, computers, etc) and were grossly underpaid and undervalued [42]. The World Wars increased the scope of "women's work" as labour shortages necessitated it. By 1938, the numbers of women working in scientific and technological roles for the US government had dramatically increased – despite overtly hostile job conditions [42]. Women were given lesser job titles such as "assistant" due to their gender [40]. And despite the large number of women working in tech, all of the leaders and managers were men [25].

Nevertheless, the women of this era remember it as a time of excitement [25]: it was a chance for them to be involved in something technical/scientific. And indeed, the World Wars also marked the birth of digital computing. Computing machines were devised in the UK for cryptographic purposes. These machines, and the hand computations done in the wars throughout the world, were commonly performed by women. ENIAC, arguably the first real computer, was announced in 1946. The plan to run the ENIAC was such: a male scientist would be the planner, deciding what was to be computed – and a low-rank, female "coder" would do the actual machine coding [18].

2.2 The Continual IT Labour Crisis: the 50s through 70s

For the men running computing labs, what was not anticipated was that the coding would actually be difficult [18]. As computers began being used for commercial purposes in the 50s, a labour shortage emerged. Computing in the 50s and 60s can be characterized by a large, shotgun approach to recruiting "good programmers" when little knowledge of what a "good programmer" was. Programming began to be seen as a "dark art" [18]. Due to the individuals who began programming at that time, programmers began to be seen as asocial [18] – kicking off a feedback loop that persists today.

Women continued to have a large presence in programming in the 50s. They contributed to the development of programming languages [25] and scientific computation [17]. But traditional gender roles in many way persisted. Women in the 50s still had to leave when they became pregnant [40]. And women hit what they dubbed the "glass ceiling": a collective barring from managerial and senior positions [17].

As computer programming rose in prominence, it became masculinized. Women were still allowed entry to the jobs due to the desperation for quality labour. However, lazy hiring practices that focused on spurious aptitude and personality tests hurt female participation in the industry [18].

Inconsistent professionalization efforts also hurt female participation by restricting what it meant to be a programmer. The men running the show did not intend to push women out of computing – instead, they simply did not consider how their hiring practices discriminated against women [18]. In short, *de facto* discrimination was the dominant driver of women out of computing.

3. WOMEN IN ACADEMIC CS

3.1 Early Days: 1960s and 70s

Computer programming stayed largely independent from academic computer science. In the 50s and 60s, CS was conducted through other departments, typically as a hobby or side-project [18]. The first CS classes were offered in the 60s, as the discipline struggled to assert itself [12]. By 1969, MIT had opened an undergraduate programme in CS – and the 70s marked the beginning of bachelor's degrees in CS offered typically through electrical engineering or mathematics [18]. It would not be until the 80s, though, that CS programmes moved into their own departments.

From the start, CS seemed like a "grab bag of various topics" related to computers and attempts to define the discipline were inconsistent [18]. Was CS about information? Analysis? Algorithms? No consistent narrative was established, though algorithms eventually became dominant.

It should be noted that the establishment of CS departments coincided with the sexual revolution in North America. While CS was opening its doors, women were asserting their rights – including those to work and study.

3.1.1 The First Generation: women who entered in the 60s/70s

As documented by Etzkowitz et al in a 1994 paper, women of different academic *generations* in STEM have had wildly different experiences in academia. In a study of 30 academic science departments in biology, chemistry, physics, CS, and electrical engineering in the United States, Etzkowitz found stark and sometimes conflicting differences between the women of different generations in these departments [20].

The First Generation of women in a given STEM department faces a very different environment than subsequent generations. Unlike today's undergraduates entering classrooms with women as minorities, these women often entered classrooms with *no other women* [20]. There were seldom other women in their field, and this continued into graduate school and faculty life. Such was the case for the majority of women who entered CS in the 60s and 70s – before CS was even an established discipline. Most came to CS via departments such as math, physics, electrical engineering, psychology, English, music, and linguistics [25].

One senior female scientist in Etzkowitz et al's study described her cohort as such: *"The ones who did [science] were really tough cookies. Now it's easier to get in. At one time it wasn't even acceptable to start. So if you started back then you were tough to begin with."*

In short, women with low self-efficacy simply did not go into that given STEM field. Only the strongest, the most focused and most ambitious stuck it out. And it led these women to expect that women had to be better than men in order to succeed [20]. Given the data that women today are subconsciously discriminated against with regard to job offers, postings, tenure applications, and collaborations (see [32, 49, 39]), it's not a surprising position to take – particularly when many of these biases were explicit and *conscious* when they began their careers. Women were underrecognized for their contributions [43], and when they were, they got "separate but not quite equal form[s] of recognition" [40].

With few other women around, these women worked in a culture which expected them to *"accept the strictures of a workplace organized on the assumption of a social and emotional support structure provided to the male scientist by an unpaid full-time housewife"* [20]. These women adopted lifestyles and approaches mimicking the traditional man, including a singular focus on research and career advancement [20]. Marriage and children were secondary, if done at all.

4. THE ESTABLISHMENT OF CS DEPARTMENTS: THE 80S AND 90S

4.1 The First Bubble: The 80s

The early 80s were also a boom-time for student enrollment in CS [47], which was linked to the rise of the personal computer. Personal computers had not been available until the late 70s; prior to then, CS was hence only pertinent to academia, military, and business.

However, by the late-80s, enrollments began dropping – and disproportionately so for women [41]. The decline was "largely the result of explicit steps taken by academic institutions to reduce CS enrollments when it became impossible to hire sufficient faculty to meet the demand." [41] Steps included adding new GPA requirements for entering CS programmes, requiring more prerequisites, and retooling first-year CS as a weeder course [41]. These actions disproportionately hurt not only female participation in the field, but participation of racial minorities as well [41]. These "non-traditional" students had disproportionately come to CS via non-traditional paths (such as via psychology or linguistics) and disproportionately lacked the prerequisites as a result. The retooling of first-year CS as a weeder course also resulted in a competitive atmosphere that deterred many women. Once again we see *de facto* discrimination pushing women out of computing.

4.2 Post-Bubble: The Early 90s

The situation for women worsened in the 90s. The personal computer led to further masculinization of computing [11]. Five reasons thought to have reduced female participation in the 90s were: the rise of video games, subsequent changes in stereotypes/perceptions of computing, the encouragement of boys to go into the field and not girls, an inhospitable social environment for women, and a lack of female role models [11].

The 90s appear to be when CS educators started worrying about female participation in CS. Before the drop in female enrollments in the late 80s, it had been fair to assume that reaching equal female participation in CS was simply a matter of time. Indeed, in the 80s and early 90s, CS was still seen as a "woman-friendly" science [20].

While women-in-CS initatives had existed in the 80s (e.g. The Anita Borg Institute was opened in 1987 [31]) – it was not until the 90s when they proliferated (e.g. The Committee on the Status of Women in Computing Research (CRA-W) was formed in 1991 [16], the Grace Hopper Celebration of Women in Computing was first held in 1994 [17]) and by the 00s they became "mainstream".

4.3 The Dot-Com Bubble: Late 90s

The birth of the World Wide Web in the 90s and its spread beyond academic/military use led to a second bubble in CS enrollments, known as the dot-com bubble. The hype of the dot-com bubble and the promise that a CS degree would lead to easy prosperity led to a resurgence in enrollments in the late 90s – particularly due to students who wanted to get rich quick. The dot-com bubble burst in 2000 – and enrollment with it a few years later [47]. Indeed, the NASDAQ has been found to be a predictor of CS enrollment at Stanford [37].

The boom-time in the late 90s and early 00s led to a return of strict enrollment controls and a spree of hiring more CS faculty [47]. Most of these new hires were relatively young, and of what we will refer to as the "Second Generation".

These boom-times also reduced the amount of service teaching: with CS programmes overburdened, CS departments had few resources and little motivation to teach non-CS students. At some universities, departments such as physics or math began offering their own CS classes to their own students – leading to CS becoming increasingly isolated from the other sciences – and from non-traditional students.

4.4 The Second Generation: women who entered in the 80s and 90s

Etzkowitz et al found that once women faculty were hired in a STEM department, *"it definitely changes the attitude of how male students react to women. They must take them seriously and this is positive"* [20]. Explicit sexist behaviour, such as public sexual joking and stereotyping decreased as a result [20]. Etzkowitz et al found there was a critical threshold at which women *in a department* begin to be treated more fairly, and blatant discrimination becomes uncommon. This appears to be at around 15% women.

The women entering this environment (in the 80s and 90s) had a different experience than the First Generation – who had had *no* female faculty when they were students[20]. The Second Generation was particularly eager about these First Generation female faculty. They had high expectations about these female faculty, and wanted to learn things from them such as *"how to dress, how to act at conferences, what to do when somebody is curt to you"* [20]. In a sense, some of these women saw the First Generation as their White Knights, to guide them through academia.

While the First Generation was preoccupied with simply getting on in a man's world, being a *woman* in a man's world was a preoccupation for the Second Generation [20]. These women were concerned about how many women there were in their programmes, hired as faculty, etc. Viewing science as only one part of their identity, these women also focused on how to balance career and family [20].

For Second Generation women, work-life balance was the key problem. Figuring out when to start a family, and seeking maternity and daycare support from their universities were priorities [20]. As noted already, many leave academia because they feel balancing both work and family care is untenable. However, more recent studies have found the decision making is complex: women who are more satisfied with their jobs are more likely to make having both academia and a family work. Women who feel they are discriminated against at work, and feel their promotion and tenure chances are unlikely, are more likely to leave the job to look after their families. [23] These women began most of the "women in science" type clubs, seeking to mitigate their feelings of isolation at work [20].

4.4.1 Conflict Between Generations

Etzkowitz et al observed that the different experiences between the first two Generations has led to a bifurcation of the women in their study's participating departments. When the Second Generation began most of the "women in science" clubs, some of the First Generation were leery of these organizations [20]. "*Fear of stigmatization led some [women] to deny the existence of gender-related obstacles. Calling attention to difficulties overcome could lead to countercharges of special privileges received*" – devaluing their hard-fought achievements that often took significantly more work than the achievements of their male colleagues [20].

Furthermore, "*frustrated by the emergence of women's issues, they regarded such concerns as indicative of a lack of commitment to science. They believed women's groups and programs [sic] to improve the condition of women harmed female scientists by making them appear 'different', and by implication less competent*" [20]. However, the sheer isolation, and blatant sexism experienced by the First Generation women led many of these First Generation women to support and lead diversity initiatives.

Advising was another source of inter-generational conflict. One female graduate student in the study reported that it was harder as an advisee of a senior woman, due to her advisor's "sink or swim" attitude. Many of the First Generation were harder on their female advisees, feeling they had to be to "prepare them to meet the higher standards they would be held to as women" [20].

5. AFTER THE DOT-COM BUBBLE

When the bubble burst, the "get-rich-quicker"s disappeared – and CS departments were left trying to get more "bums in seats". Enrollments did not recover again until the mid 00s – and have been on the rise since [47]. Indeed, recent reports paint enrollments at record numbers, even greater than the peak of the dot-com bubble [38].

Overall, a pattern of cyclical enrollment emerges. Boom times lead to more students, then more enrollment controls; bust times lead to more outreach. Bust times also result in disproportionately many women leaving the field, or not going in at all [47] – indeed, as of 2011, 18% of CS students are female [38].

5.1 The Third Generation: women who entered in the 00s/10s

The Etzkowitz et al paper was published 20 years ago, when the Second Generation was still growing. Women entering CS since the 00s have had a different experience of computing culture (arguably this has been true since the late 90s depending on the CS department). For the first author of this paper, who entered CS in 2007, approximately 20% of the CS faculty were women, predominantly women of the Second Generation. They have families and the Women in CS club was (and still is) highly visible and active, as is their delegation to Grace Hopper, as well as scholarship and research opportunities designed for women in CS.

The early 00s marked an era of focus on increasing female participation in CS. Margolis and Fisher's influential *Unlocking the Clubhouse* was published in 2002; this year also marked a SIGCSE bulletin special edition highlighting research on women in computing [26, 14]. For many (if not most) women of the Third Generation, their departments have made explicit efforts to improve the experience of women in their classrooms. The work by Margolis and Fisher, and others such as Joanne Cohoon, Maria Klawe, and Camp and Gurer, led to many departments working to remove *de facto* barriers for their female students. Follow-up studies at places that have implemented Margolis and Fisher-style recommendations have found a cultural shift that helps female students [9, 3].

And indeed, for female students entering CS in the 2000s and 2010s, there already exists a strong social network for women in computing. This network has been designed mostly by Second Generation women – and mostly around what the Second Generation women had wished they'd had when they entered the field. This is important as, again, people may take for granted the experiences of other generations.

For example, the findings we see in the 2002-era women-in-CS papers will discuss access to physical computers [26, 36]. For most women entering a CS classroom, computers have been ubiquitous for most of their life. Indeed, for these women, the Internet has been a world that girls use more heavily than boys [24]. Growing up, Third Generation girls performed equally well in science and math as boys. Finally, the Third Generation is far removed from the explicit sexism that the First Generation experienced.

5.1.1 Barriers for the Third Generation

Despite many improvements in the culture, female enrollment in CS hasn't significantly improved since hitting that 15% critical mass. Despite the uptick in the mid-80s, the numbers are now down to around 18%. Clearly, critical mass isn't enough on its own to get female participation to 50%. Concerningly, one issue affecting women in CS is backlash for the women-in-CS initiatives. Even in the Margolis and Fisher study era, female students have reported harassment along the lines of "you're only here because you're a girl" [36]. The stigma of receiving preferential treatment in science has been documented as decreasing self-efficacy for its recipients [52], decreasing the perceived competence of its recipients [30], and causing stereotype threat for its recipients [29, 48].

Implicit sexism appears to be the dominant barrier for women of the Third Generation. While *de facto* discrimination and explicit sexism (particularly sexual harassment) still occur, they are no longer predominant. The subtle biases that have been there from the beginning remain, such as:

- The CV of a woman applying to a STEM job is viewed as demonstrating less competence than the same CV with the name changed to a male name [39, 49].
- Conference abstracts with female authors are viewed as being of lower quality than if the abstracts are changed to have male authors [32].
- Articles written by women are cited less than those by men [50]. Women are less likely to be listed as either first or last author on a paper [53]. Similar disparities exist in funding [34] and earnings [45].

- Women are more likely to be promoted based on past accomplishments, whereas men are more likely to be promoted based on potential [6].
- Letters of references for female job candidates are more likely to use gendered wording ('warm', 'kind', etc) which in turn hurts a candidate's hireability [51].
- The language used in job postings has also been found to favour men: gendered wording is common, and women are less likely to apply for jobs using such wording [22]. An entire blog, "Tech Companies that Only Hire Men", which features job postings with gendered language in IT, has frequent entries [1].

With these implicit biases come other social-psychological barriers for women in CS, such as stereotype threat [33], tokenism [7], and benevolent sexism [28]. These subtle forms of sexism all continue to subtly push women out of CS through a "death of a thousand papercuts". Insidiously, many Third Generation women do not perceive any gender-based biases against them, and are unwilling to take action on what they consider a "problem of the past" [55].

6. DISCUSSION

In looking at how female participation in CS has changed over time in North America, we also gain some insight as to why female participation is different around the globe. CS is female-dominated or at gender-parity in places such as the Middle-East [27, 21], Eastern Europe [21], and South-East Asia [19]. A 1994 study by Barinaga set out to explain the cross-cultural differences in female participation in STEM. She found five positive factors, three of which are supported by the history of CS in North America [5]:

1. More women are present in countries with **recently developed science capabilities**. The academic culture is relatively unentrenched, and no "old boys network" has come to dominate. When CS was new, we saw more women in the field. This was true both in industry (female computers) and in academia (the 80s).
2. More women become scientists in a culture where **science is perceived as a low status career**. It is established in sociology that the lower the status and pay an occupation, the more likely it is that women will be found there [5]. When CS meant being a "computer" or a lowly "coder", women played these roles. When CS rose in prominence – such as during the 60s, and during dot-com boom, the percentage of women entering CS decreased.
3. For a given culture, if a woman of high class has higher social standing than a man of low class, we see more women in science. **Privilege** hence matters – and is linked not just to gender but also class and race. Women in CS are disproportionately from relatively affluent backgrounds [36]. Women of colour are disproportionately underrepresented. (Indeed, a weakness of this paper has been our focus on the history of *white* women in CS – more needs to be done to document the history of racial minorities in the field.)

While it is difficult to make CS "new" again, reducing the entrenched culture has proven benefits for attracting non-traditional students [9, 14]. It should also be noted that CS is not homogenous: fields such as gaming and security [46] lag behind with regard to female representation, and explicit sexism continues to be a problem.

What the history of women in CS shows is that this is probably best tackled one barrier at a time. The removal of *de jure* discriminatory policies allowed women to become "computers" and to attend engineering schools [40]. Such policies still exist in other countries, such as Iran, where women are barred from studying CS [44].

Once the First Generation of women arrived, explicit sexism was the next problem. When a critical threshold of women were present, explicit sexism decreased markedly in frequency. The change in culture produced the shift to the Second Generation, who focused on being both a woman *and* a scientist. *De facto* discriminatory policies have been the issue for these women, such as entrance requirements that disproportionately bar women from studying CS, and a culture that leads to social isolation for many women.

The Second Generation women have established a network of support for female students, from Grace Hopper to local women in CS clubs. While *de facto* discriminatory policies still exist, a larger problem facing the Third Generation are the subtle, social-psycological biases working against them.

Implicit sexism may be difficult to identify and fight, but it is possible [4]. Blind reviews in scientific journals, for example, lead to more women and minorities publishing [10]. Where possible, scholarships and research grants should use blind reviews. Social-psychological interventions have been found to reduce stereotype threat [54]. Changing the stereotypes about CS in popular media leads to women to have more interest in the field [13].

Meanwhile, enrollments in CS are now skyrocketing yet again: the 2012 Taulbee Survey found that CS enrollments have risen for the fifth straight year [38]. Facing packed classrooms and overburdened teaching resources, some CS departments are once again considering cutting interdisciplinary programmes and service courses. We hope that CS departments will maintain these initiatives, given their known benefit for women [14].

CS has come a long way since the day of female "computers", and progress has not been linear. Barriers remain, particularly for women of colour and women of lower class. Tackling these issues requires an understanding of all the forces at work – including our past.

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Chapter 4

The Current Enrolment Boom: Policymakers Are Not Considering Diversity

This chapter presents a short paper I published at RESPECT 2016 [158]. This was part of a larger research project on how professors are being affected by the enrolment boom.

The main contribution of this paper is observing that gender diversity is not being discussed in CS department discussions about how to respond to the enrolment boom. We saw in the previous chapter, we saw that each time computer science experienced had an enrolment boom, the percentage of women has decreased. And unsurprisingly, not considering diversity has negative implications for gender diversity [49]. Since this paper was published, preliminary statistics indicate the percentage of women is back on the decrease [44].

In terms of my theoretical journey, I had gone into the larger research project expecting to see micropolitics in action: professors working with or against each other to pass particular policies. There is little research on policy practices in CS departments, but Gruba et al [89] had found that CS curricular changes were driven primarily by influential and outspoken individuals in CS departments.

Surprisingly, this did not emerge in my data. "Influential or outspoken individuals" were most commonly cited as a minor factor in policy discussions, and "political support/opposition within the department" was not a factor. This led me to rethink my theoretical lens. There are multiple approaches to micropolitics; I had been favouring a Marxist approach that would expect there to be influential individuals or coalitions. Another approach to micropolitics is more Weberian, and focuses on leadership and cultural values. Reconsidering the (Neo-)Weberian micropolitical literature in light of data more consistent with that approach led me to learn about Neo-Weberian closure theory.

This paper combined with my history of women in computing in chapter 3, together indicate that not only does policymaking play a role in gender diversity in computing education, but that its effect is in part from policymakers not considering diversity.

How CS Departments are Managing the Enrolment Boom: Troubling Implications for Diversity

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***Abstract*—Enrolments in North American undergraduate computer science have been booming in recent years, and many CS departments have been struggling to meet student demand. We surveyed 78 CS professors, instructors, staff, and administrators to see how the enrolment boom has been affecting their practice; and to see how departments are responding in terms of policy. We asked participants to tell us what factors were being considered in their department's policymaking using a page of open-ended questions. Only one participant of 78 noted diversity as a concern. We then gave them a list of factors we thought could affect their department's policymaking, including diversity. After this prompt, more participants reported diversity was important (n=5). We found that policymakers are favouring solutions which are intuitive to them, rather than looking for examples from the literature, similar institutions, or the history of their own institution. Problematically, many of these favoured approaches have historically been linked to having a negative impact on demographic diversity in CS programmes. This could exacerbate the low participation of underrepresented groups in computer science, and undermine efforts to improve diversity.**

I. Introduction

Computer science is an unusual scientific discipline in that the percentage of women in the discipline in the West is *worse* than it was in the 1980s. With the percentage of women in CS currently around 18% in the West [1], much effort has been going into improving gender equality in the discipline.

The underrepresentation of women in Western CS is due to a complex interaction of social, cultural, and political factors. Social factors include the changing stereotypes about technology use, such as the gendering of computer technology [2], [3]. Cultural factors refer to the culture of computing itself, which promotes "hacker culture" [4]. Finally, political factors refer to the policies used in computer science institutions, which can affect female representation.

Historically, CS has had two "enrolment booms" where the numbers of CS undergraduates sharply increased and later decreased. In the past, the approaches taken by CS departments to manage enrolment booms have affected student culture and learning [5], [6]. These approaches include restricting access to classes and majors as well as creating large "weeder" courses. These policies detrimentally altered student culture to be "defensive" in the terminology of Garvin-Doxas and Barker [7], contributing to the low participation of women [5].

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With enrolment booming again, we felt it was important to ask how CS departments are responding in terms of policy, and if diversity is being considered.

II. Methods

We surveyed CS professors in North America about what their departments are doing about the enrolment boom. Our survey had four pages:

1) Details on the participant: contact information, their role, institution
2) Has their undergraduate CS programme been experiencing an enrolment boom (yes/no). If so, how does it compare to the dot com era (greater/lesser/don't know)?
3) Open ended questions
   a) How has the increase in enrolments affected your teaching?
   b) How has the increase in enrolments affected your department as a whole?
   c) What is currently being done and/or planned to handle the increase in enrolments?
   d) What do you think about the policies/approaches your department has been implementing/discussing?
4) Pre-established factors and reflection
   a) What factors would you say are influencing your department's strategies for handling the increase in enrolments? To what extent? (a list was provided of pre-established factors, and participants indicated whether each was a major factor, medium factor, etc; 'diversity' was one of several factors such as 'classroom capacity' and 'fiscal resources')
   b) Out of the list of factors above, including any ones you added, which do you personally feel are neglected in your department's discussions but ought to be considered? Why? (Open-ended)
   c) Is there anything else you'd like to tell me about your department's handling of the enrolment boom? (Open-ended)

We determined a list of factors based on the literature [8], [9] and then, after piloting the survey on ten colleagues, we added "A sense of urgency" to the list. This list was then randomized for the presentation to each participant to mitigate any bias coming from the order of the factors.

We intentionally asked participants how the boom had been affecting their teaching/department *before* listing any factors we had identified from the literature. This was so that we would not bias participants' responses to those identified factors. However, we also wanted to get a sense which factors were most prevalent, and if participants' answers would change after seeing a list of factors from the literature.

We solicited participants from the SIGCSE mailing list, the CSEd-research list, the cssei-interest list, the Facebook group on CS education, the reddit community on CS education, and on Twitter. We asked participants to share the survey with their colleagues. A total of 87 responses were collected, 78 of whom were completed, and with 53 answering every question. For our qualitative analysis we only used the 78 complete submissions.

Respondents came from a total of 65 different institutions, 51 of which had only one respondent. 3 institutions had two respondents; two had four respondents; and one institution had five. We had no participants from our own institution.

III. Results

In the open-ended questions, we found eight approaches used by CS departments to handle the enrolment boom. In order from most common to least common (as indicated by the number of participants who mentioned it):

1) **Altering course offerings (39):** increasing class sizes, more sections, reducing elective offerings, etc.
2) **Hiring (28):** faculty, contingent faculty, TAs, etc.
3) **Gatekeeping of classes (8):** restricting access to classes by programme, directing non-majors to other classes, “weeding out” students, etc.
4) **Course delivery changes (4):** using flipped classes, using more web exercises, more autograding, etc.
5) **Gatekeeping of major (3):** increasing existing thresholds to enter major or creating such thresholds, etc.
6) **Faculty management (3):** teaching overloads, changing credit for teaching, etc
7) **Space (3):** acquiring new classrooms, moving to larger buildings, etc.
8) **Other programmes (2):** creating partner degrees (e.g. data science), increasing graduate programmes, etc.

Only one participant made any mention of diversity in the open-ended questions on page 3: *“We are asking for new tenure lines and hiring multiple visitors. Not much else we can do without harming enrolment of women and underrepresented minorities.”* (P57)

After priming, five participants mentioned the diversity issue, saying either that it was being neglected or that it was an important issue. For example: *“I’ve recently been considering the impact of “weed out” classes on diversity in the major, and that may become more of an issue as enrolments increase, incoming student quality potentially declines, and the use of weed out courses as a tool for enrolment management gains more consideration. This issue has not been explicitly considered in the past, but I will be keeping it in mind.”* (P20)

With regard to the factors we had explicitly asked about, they were ranked:

1) **Most commonly a “major factor”:** Classroom capacity, Fiscal resources, Quality of undergraduate education, Faculty/staff availability and/or workloads, Use of contract/sessional/adjunct instructors and teaching assistants
2) **Most commonly a “medium factor”:** Effects on student culture and experience, Quality of students, Political support/opposition from outside the department, What has/hasn’t worked in the past
3) **Most commonly a “minor factor”:** A sense of urgency, University/government requirements and regulations, *Demographic diversity of student body*, Capacity to teach non-CS students, Influential or outspoken individuals, Feedback from students, Ability to provide interdisciplinary courses/programmes, What other institutions are doing
4) **Most commonly “not a factor”:** Political support/opposition within the department, The education research literature

IV. Discussion

Our results indicate that diversity is considered a minor issue to CS departments when it comes to handling the current enrolment boom. More positively, the related factors of “Effects on student culture and experience” and “What has/hasn’t worked in the past” were ranked most commonly as medium factors. However, “Quality of students” was also listed as a medium factor, and could indicate that gatekeeping is a higher priority for some departments.

Perhaps more troubling than the low ranking of diversity was that “The education research literature” was most commonly ranked as “not a factor”.

Because we recruited participants from CS education communities, our participants are not likely to be representative of all university CS educators. However, our participants are thought to be *more* likely to care about diversity and classroom culture than faculty who are not members of CS education communities. Our study likely gives an upper bound on how much diversity is considered in enrolment boom discussions.

It is clear that more needs to be done to convince CS department policymakers to consider diversity in how they manage their enrolments.

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Chapter 5

The Historical Context Revisited: The Occupational Closure of Computing

In my intellectual journey to question why gender diversity efforts in CS have not had more of a macro-scale effect, it soon became clear that I needed to understand what the root causes are of why CS is so gendered. The paper I feature in this chapter presents and illustrates the theoretical understanding I developed of why CS is gendered.

The paper in this chapter is not yet published, though at the time of writing is under review. The copy of the paper I have in this thesis reflects the latest version of the paper.

5.1 A Neo-Weberian Lens

Through working on the paper in the previous chapter, I had realized that a Weberian understanding of conflict theory would be beneficial for me, as my participants described conflict in CS department policymaking as based over values rather than resources. This led me to learning about closure theory. Reading Witz's "Professions and Patriarchy" was an "aha" moment for me in my research process. Witz describes the history of four medical professions and how they masculinized/femininized over time, building a feminist approach to closure theory. In particular, her history of the masculinization of radiography struck me for its parallels to the history of early 20th century programming. It was an exciting moment for me in my intellectual journey.

5.1.1 The History of Radiography

I read Witz's history of radiography some years after writing the history of women in computing that I presented in chapter 3. I kept noticing the parallels as I read Witz's account.

As Witz describes, radiography work began in the 19th century as a task done by nurses. By 1915, the Nursing Times referred as x-ray work as nurse work. Nurses could get x-ray training, and nurses began to take charge of x-ray departments [220].

The occupation grew rapidly in the 1920s-30s. Male radiographers created a diploma programme in 1921 and assumed this formalized route would exclude women, but by the mid-1920s radiography had become female dominated [220]. Partly this was because of a strategy of inter-occupational demarcation: a female radiographer would take the x-rays and then a a male radiologist would interpret the images. As taking the images required interaction with a patient, it was seen as "patient care", rather than the technical skill of the radiologist [220]. There is a parallel here with the WWII-era system where a male scientist would plan what was to be done with the computing machine, and a female "coder" would have the task of doing the machine coding [66].

One reason for the large number of women was that the training to become a radiographer was relatively short. It was hence popular with women looking for a "quick return to a career" [220]. By 1935, 60% of the Society of Radiographers were women [220]. Again, we see a parallel with the programming schools of the 1960s [2].

Male radiographers saw the presence of women in the profession as the cause of their low salaries. Per Witz: "low salaries were identified as a problem for the male radiographers rather than the female radiographers who actually received them." [220] This led to the intensification of credentialist tactics.

By the late 1930s, male radiographers were describing their "academic outlook" and their superior technical skills over female radiographers [220]. They began a discursive appeal to the engineering pedigree of radiography skills, and formed a discursive equivalence between "technical competence" and masculinity [220]. The male radiographers denigrated the training of nurses as "elementary" [220]. Through promoting these discourses and blocking female-dominated pathways into radiography, men came to dominate the profession.

5.1.2 Using Closure Theory

As it turns out, I was not the first to realize that occupational closure theory was a good fit for explaining the gendering of computing. Tijdens' history of Dutch IT [196] and Dryburgh's study of women entering Canadian IT jobs through "alternative pathways" [62] had both examined the merits of multiple theories and concluded closure theory was most apt for the computing context.

However, neither work provided an explanation of the historical variations in the US/Canadian context using closure theory, nor fully investigated the mechanisms of how computing is closed. Two of my contributions in this paper are to address both of those issues. Furthermore, I also contribute insight on the dual closure of computing, which had been not previously addressed.

I also felt more could be done to link closure theory to the existing CS education literature. In my paper I note that the successes at Carnegie Mellon and Harvey Mudd are examples of successful usurpationary closure. Closure theory also is consistent with the Generation CS report that found a correlation between whether a CS department thinks about gender diversity in their policy making and the gender balance of their CS programme [49].

Writing this paper also gave me an opportunity to update the ITiCSE history paper from chapter 3. I was keen to do this since a number of new historical sources had emerged (including Abbate's "Recoding Gender" [2] and Hicks' "Programmed Inequality" [109]). I had found more sources that I had previously not noticed, particularly works not cited by the CS education literature (such as Sturman's thesis [193] and Tijdens' history of Dutch IT [196]). While the broad strokes of my first history paper still hold true, I felt I could do better and add in nuances uncovered by my new sources. This chapter presents a substantial rewrite of my first history paper, to accommodate those new sources.

Gendered Participation in Computing Education: What Educators Should Know About The Historical Sociological Trends

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ARTICLE HISTORY
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ABSTRACT
Women currently comprise around 15% of computer science students in the United States and Canada; CS is the only STEM field where the percentage of women has decreased with time. This paper seeks to understand the historical context for why women are underrepresented in modern Western computing, to inform educators on how the status quo may be changed. In the sociology community, Neo-Weberian closure theory has been used to explain how CS has become gendered. In this paper, we provide an introduction to closure theory, and reexamine key works of historians and CS education researchers through the lens of closure theory. In doing so, observe that policies and discourses have historically acted as levers to close the field off — but which also have the leverage for broadening participation.

KEYWORDS
Computer science education; higher education; history; sociology; sociology of education; women in STEM

1. Introduction

It is no secret that computer science (CS) has a gender diversity problem. In the US and Canada, to which we will scope this paper, women currently comprise around 15% of CS undergraduates (Ashcraft, Eger, & Friend, 2012). Among the science, technology, engineering and mathematics (STEM) fields, CS is the only discipline where the percentage of women students has decreased since the 1980s. The field has accumulated a stereotype of being for male white/Asian nerds, and requiring solitary work. Unsurprisingly, this stereotype is unattractive to many people, particularly women (Varma, 2007a).

Many CS educators are keen to change the gender dynamic in their classes and programmes. In the CS education community, a literature has emerged on how to encourage women to take CS (Ashcraft et al., 2012; Guzdial, 2015) and persist in the field (DuBow, Weidler-Lewis, & Kaminsky, 2016; Garvin-Doxas & Barker, 2004). CS education researchers have studied why women do and do not choose to major in CS (Carter, 2006; Margolis & Fisher, 2003). This literature is often informed by psychology, and focuses on the choices and biases of individual players.

While psychology can give many insights to individual-level behaviour, we need the epistemic tools of sociology to understand what is occurring at the population level. CS was once female-dominated in the West, and continues to be female-dominated in some non-Western countries (e.g., Malaysia). Psychological theories such as expectancy-value, subtyping, and stereotype threat all fall flat as explanations for understanding the historical and geographical variations. Yet CS education as a field does not commonly use theories or frameworks from sociology (Malmi et al., 2014). In order for CS educators to make systemic change to our field, we need to address the roots of gender inequality in computing, rather than only its individual-level manifestations.

Fortunately, there is literature in the critical feminist sociology community on why CS has become gendered (i.e., socially associated with a particular gender). However, this literature is not cited by the CS education community. Our first goal in this paper is to inform CS educators about what critical sociologists have to say on the topic of the gendering of computing. Sociologists such as Tijdens (Tijdens et al., 1997) and Dryburgh (Dryburgh, 2000) have argued that closure theory is the most apt social theory for explaining how computing is gendered. We will provide an introduction to closure theory, and how closure theory explains the history of how computing is gendered.

A second goal we have in this paper is to connect the social theories used by critical sociologists of computing to what historians have written about computing. A number of histories of computing have been written in recent years, shedding light on how computing came to be gendered. However, historians do not write their findings in terms of social theory. A key contribution of this paper is to add a layer of social theory to their works — in this case, feminist occupational closure theory.

This theoretically-grounded understanding is useful for identifying the root causes of CS's gender issues and, in turn, useful for educators to focus on what to change.

2. Background Information

2.1. *Sociology*

Sociology is the scientific study of societies. Most simply, a society is a *structured* group of interdependent individuals; societies are typically brought together by a geographic or social commonality. Examples of structures include social stratification (e.g. class structure, caste systems), social systems (e.g. economic system, legal system), social institutions (e.g. schools, prisons), and other forms of social organization (e.g. gender roles, families). Societies can have multiple, overlapping *cultures*; a culture refers to a set of beliefs, practices, values, etc.

At the heart of sociology are *social theories*: analytic frameworks to explain, understand, and/or predict social phenomena. In our case, the social phenomenon we are concerned with is the gendering of computer science.

There are many schools of thought within sociology. The one we use in this paper is critical theory, which foregrounds conflict in society and criticizes power structures. More specifically, we write from a critical feminist standpoint: using critical theory to focus on gender-based conflict and power structures.

Sociologists approach historical research differently than historians. Sociologists generally focus on the historical social forces and explicitly linking them to social theory. Historians, in contrast, do not explicitly work with social theory; while some historians may be influenced by social theory, their writing does not explicitly call in or link to social theory. In this paper, we will be following the sociological tradition, through examining how historians' findings relate to social theory.

2.2. *Glossary of Gender and Work Terminology*

Before we launch into an introduction to the sociology of work, it may be helpful for many readers to first familiarize themselves with some common terms used when describing gender-based discrimination and segregation in the workplace:

De jure discrimination refers to institutional discrimination for/against a given social group that is codified in law/policy. E.g. a law that women cannot vote.

De facto discrimination refers to institutional discrimination which is not explicitly codified in law/policy, but results in discrimination nevertheless. For example, a law which states that one needs to be literate in order to vote in a society would be an example of de facto discrimination if only boys/men are given access to a basic education.

Horizontal segregation in the workforce refers to segregation across occupations. E.g., when women are only permitted to be nurses and men doctors.

Vertical segregation in the workforce refers to segregation within an occupation such that one group dominates the highest status jobs. E.g., teachers are predominantly women and principals are predominantly men.

Gender essentialism refers to the notion that there is a universal and innate "essence" to each gender, from which gender roles emerge. Gender essentialism is typically contrasted with:

The social construction of gender refers to the notion that the idea of gender is something that is created by society, rather than something that is innate and immutable. Seeing gender as socially constructed explains how gender roles vary culture to culture as well as historically.

Discourse refers to the combination of language use and other social practices (e.g. behaviour, clothing, customs) to perform and "pull off" being a member of a particular discourse community (Gee, 2014). This can be used to understand gender as a discourse. In this lens, gender is something you perform through your appearance, manner of speaking, etc. It can also be used to understand other social groups; for example, "computer scientist" can be seen as a discourse.

Benevolent sexism is when women are reduced to being all the same, though presented in a positive way; e.g., "women are so good at collaboration." It is inherently essentialist. Psychology research has found that benevolent sexism is linked to hostile sexism: the more that people think of women as all being the same, the more likely they are to espouse hostile sexism (Hammond, Sibley, & Overall, 2013). Benevolent sexism is a form of benevolent prejudice; benevolent racism would be another example of benevolent prejudice.

First-wave feminism occurred in the 19th and early 20th century, and focused on women's right to vote, property rights, political office, and dismantling other *de jure* forms of discrimination.

Second-wave feminism occurred in the 1960s–1980s, "focusing on reducing inequalities in sexuality, family, the workplace, reproductive rights, de facto inequalities, and official legal inequalities." (Wikipedia contributors, 2018)

Third-wave feminism began in the 1990s and reflected a movement away from essentialist notions of gender, as well as toward considering how gender discrimination intersects other identities (e.g. race, sexuality, disability).

2.3. *Sociology of gender, work, and education*

There is a rich literature in sociology on how and why particular occupations and disciplines become gendered. By "**gendered**" we mean that it has societal associations with a specific gender — which can cause, or are the result of, a skewed gender ratio.

Many occupations and disciplines have historically changed how they are gendered. For example, medicine had historically been female-typed in the West as being part of domestic labour; in the 19th century, medicine professionalized as the growing middle class developed a preference for paid, formally trained doctors (Witz, 2013). The professionalization process explicitly excluded women — but women have since been fighting to participate in medicine, making large inroads in modern medicine.

Three major theories are used for explaining how an occupation is gendered:

(1) **Neo-classical human capital theory (NCHCT)** focuses on the employer; e.g. on how employers may avoid hiring women due to expected family responsibilities, or how employers may hire women as they have lower wage costs when it is socially acceptable for employers to do so (Anker, 1997). NCHCT predicts that during times of labour shortage, employers will hire beyond gender boundaries.
(2) **Occupational segregation theory** focuses on the workplaces and the social norms there. In patriarchal societies, the norm is that women should not exercise authority over men (Bergmann, 1986). For example a workplace may have vertical segregation (only men at the higher position jobs), or horizontal segregation (given jobs are only held by people of a given gender). Concepts such as tokenization (Kanter, 2008) further explain how the sex-typing of tasks is upheld even when organizations promote diversity.
(3) **Occupational closure theory** focuses on how groups define their occupational boundaries. These processes include policies on how to recruit and train new members, educational accreditation, licensing processes, lobbying and advocacy efforts, and codes of conduct (Witz, 2013). Occupations seeking to improve their status in cultures where masculinity is valued over femininity will favour policies and discourses to promote the occupation's alignment with groups and values that are male-typed, and exclude groups and values that are female-typed.

2.3.1. Sociology of the Gendering of Computing

Tijdens examined the history of Dutch IT work from the 1940s to the 1990s. Over this period, the percentage of female workers not only changed but both increased and decreased multiple times; IT occupations continuously had a masculine image; the number of workers grew; entry requirements changed significantly; organizational settings changed; and, some of the occupations went into a process of professionalization (Tijdens et al., 1997). Tijdens compared how different theories were able to explain the Dutch case. In looking at hiring patterns in the 1970s, Tijdens found that employers only recruited men during a time of shortage — and in the 1980s, employers recruited women during a time of increasing supply; this is inconsistent with NCHCT. Tijdens also observed that the flattening of hierarchies in tech companies, and the increase of women programming (albeit as end-user programmers) did not fit with the occupational segregation theory. Meanwhile, occupational closure theory was consistent with all of the phenomena that Tijdens observed.

Dryburgh then studied the Canadian context during the dot-com era, interviewing women entering computing jobs through "alternate pathways." Dryburgh also compared multiple sociological theories and concluded that closure theory not only was the best fit for her data, but also explained the larger literature on women in computing in North America (Dryburgh, 2000).

2.3.2. Occupational Closure Theory

Occupational closure theory is a specific case of *social closure theory. Social closure* refers to the process (and state) of social groups creating a boundary around themselves, establishing who is and who is not in this group. These closed groups can then maintain their resources through the exclusion of those not in the group (Parkin, 1981). The concept was first articulated by 19th century sociologist Max Weber, who suggested that nearly any group attribute, such as as race, language, social origin, or religion, could be seized upon to use for the monopolization of specific (usually economic) opportunities (Parkin, 1981).

In Witz's occupational closure theory, there are three types of closure:

Exclusionary closure the attempt of one group to secure itself a privileged position at the expense of another subordinate group. An example of a policy approach to exclusionary closure is the 1858 Medical Registration Act in Britain, which banned women from the registration process for doctors.

Witz notes two important strategies for exclusionary closure of an occupation: **exclusionary strategies** to make the occupation more difficult to enter, and **demarcationary strategies** to change the boundaries of the occupation. Put another way, exclusionary strategies work vertically; demarcationary strategies work horizontally.

A discursive example of a demarcationary strategy would be when doctors used a discursive tactic to deskill midwives: only obstetricians had the "technical skill" to handle an "abnormal" labour.

Usurpationary closure is the use of power "upwards" by a subordinate group to get a slice of the pie (Parkin, 1981). Examples include protest movements, civil rights legal challenges, strikes by labour movements, and collective action by political groups. Witz classifies usurpationary tactics as either equal rights–focused (e.g. legal challenges to allow women to study in "normal" medical schools) or separatist (e.g. the creation of the London School of Medicine for Women). Though usurpation is usually done as a collective, it can also be done on an individual level. For example, when Britain did not allow women into its medical schools, some women would become licensed doctors in countries that were willing to train them, and then the women would practice medicine in Britain with foreign credentials.

Dual closure is when a subordinate group uses both exclusionary and usurpationary methods (Witz, 2013). E.g., when nursing was professionalized in the UK, the educational and credentialing requirements were set so that low-class women would not be able to become nurses. This was done to improve the status of nursing through improving its class status, but also excluded low-class women.

Dual closure can also operate between occupations. E.g., when obstetricians were claiming dominance over midwifery, female doctors advocated for this change in order to demonstrate their greater status over midwives. While this helped female doctors gain legitimacy, it also promoted the exclusion of other women from paid work.

3. Method

In this paper, we provide a history of women in CS using the lens of occupational closure theory. We focus on the historical social forces, rather than stories of individual women. Our goal is not to provide the most comprehensive review of the history of women in CS, but rather to illustrate a social-theoretic understanding. Hence, we identify and focus on key works of historians and add a closure theoretic lens therein.

The point of adding the closure theoretic lens is to yield further insights about these existing works; it is intended to complement, rather than replace, the existing theoretical lenses of the source works.

4. Closure of Industrial Computing

4.1. *Rossiter: Women as Computers from the 1820s to 1910s*

To begin our history, we rely heavily on Rossiter's *Women Scientists in America*. It is the most comprehensive book on the history of women in science before the World War era. Rossiter's work has informed other histories of this time period, such as Grier's *When Computers Were Human* and Light's *When Computers Were Women*.

Rossiter's explicitly-feminist historiography focuses on the social and economic influences on opportunities for women to enter science. She discusses both vertical and horizontal segregation in science, and the strategies women used to expand their opportunities. Her history was published before Witz's book, and so does not use the language of closure.

4.1.1. The Emergence of Women as Computers

There is a long history of upper class women taking up mathematics and computational techniques as a hobby (e.g. Ada Lovelace, a countess in a family of mathematicians (Gürer, 2002)). However, this was strictly limited to only the upper echelons of society, and it was not until the 19th century that we see formal paths for women to be trained in mathematics.

As first wave feminists began organizing in the 19th century to fight *de jure* discrimination, one of their battles was for access to education. Women successfully lobbied for for access to higher education using an argument that it would "produce better wives and mothers".

This led to the creation and rise of women's colleges in the United States. As these colleges became established, it became accepted that women of privilege should possess a basic understanding of science and math as it was now considered "necessary for motherhood". This was a trend for white women of wealth; most women who studied science in the 19th century were the daughters of scientists and other intellectuals.

But while these colleges gained acceptance in American society, there were few job opportunities for the women scientists graduating from these colleges. Women pursuing an intellectual career were expected to be single or "in no danger of marrying"; marriage meant resigning from a PhD or their job. Teaching at the women's colleges was the main option. Working as a "computer" was another option (Light, 1999). This work entailed performing hand calculations for scientific, governmental, business or military purposes — work that without modern calculators involved skill in breaking complicated calculations into simpler steps, and mathematical knowledge.

During the US Civil War, opportunities expanded for women to work as computers

(Grier, 2013). In particular, computers were needed to work on ballistic calculations for the war effort when the men who had previously working as computers left for the battlefront.

4.1.2. After the American Civil War

1870–1900 marked an era of slow infiltration of women into traditional (male) schools and workplaces. Women began entering doctorate programmes at traditional institutions. Most universities were hesitant to allow the women into the PhD programmes, but would instead admit them as "special students" and give them bachelor's degrees. Engineering schools remained resistant to women. By 1910, women were starting to establish a presence in science at traditional institutions, but there was no equality in employment, and jobs remained deeply sex typed.

With the slow usurpation of women into science came the corresponding demarcationary rise of "women's work" in science. So-called women's jobs typically were "assistants" to scientists, or working as computers for larger groups. These women were systematically ignored in the larger scientific community and were left out of lists of scientists, conferences, and histories (Rossiter, 1993). From 1911 onward there were overt efforts to reduce the number of women in science (Rossiter, 1982).

A race emerged between the usurpationary efforts of women to get into science and the exclusionary efforts of men to keep science masculine. Once women were permitted in academia, they were relegated to lower-status positions and their contributions excluded from what was considered science.

It should be emphasized that computation was considered "women's work" in the 19th and early 20th century. At the time, quantitative methods were considered "low" enough that women could do them, while qualitative methods required "the intellect of a man" (Luker, 2008). The reversal of the status (and gendering) of quantitative vs. qualitative work in the social and biological sciences happened well into the 20th century (sometime between the 1930s–50s) (Luker, 2008).

4.2. *The World Wars: 1910s to 1940s*

During the 1920s, women in academia were still largely kept to the women's colleges (Rossiter, 1982). The colleges, however, provided a place to organize campaigns for change. Women made an usurpationary argument using evidence from psychology and anthropology that women too were capable of science and math (Rossiter, 1982).

The 20s and 30s marked an expansion of government-employed women scientists, who were assigned "women's work" (assistants, computers, etc) and were grossly underpaid and undervalued (Rossiter, 1982). In many countries, bans were lifted on married women working in civil service positions (Hicks, 2017). Justified by labour shortages, the scope of "women's work" was increased during the world wars.

As Abbate notes, labour shortage is a social construction, reflecting assumptions about what types of people are suitable for particular positions. Other solutions could have been used to address the issue of supplying both fighters and workers: why not recruit women to serve in combat and have more men remain in their jobs? Why not allow black men into skilled wartime positions rather than confining them to the lowest paid jobs? Increasing the scope of "women's work" for white women to handle the labour shortage was the most palatable option to the political and business leaders of the day, reflecting cultural attitudes and priorities (Abbate, 2012).

The women working in computing positions through the military were required to do so through non-combat positions, and were viewed by military leadership as an expendable "auxiliary force" (Hicks, 2017).

By 1938, the numbers of women working in scientific and technological roles for the US government had dramatically increased despite overtly hostile job conditions (Rossiter, 1982). Due to their gender, women were given lesser job titles such as "assistant" (Reinish, 1999). And despite the large number of women working in tech, all of the leaders and managers were men (Gürer, 2002). Indeed, women were told that only men could get professional ratings (Abbate, 2012). Women were similarly unable to be promoted to the position of cryptographer, even when they had higher levels of education than their male colleagues (Abbate, 2012).

Ultimately, while WWII increased the scale and sophistication of computing work, the same gendered pattern persisted from pre-war time: a male scientist/cryptographer did the "planning" while a female "assistant" performed the calculations or coding.

4.3. *Abbate: The Masculinization of Computing, 1950s to 1970s*

Abbate's *Recoding Gender* is the most comprehensive source available on the history of women in US industrial computing after World War II. For this section we will draw heavily on this work, supplementing it with other sources. In Abbate's history of how computing masculinized during this period we see two themes: working practices, and discursive positioning.

Adding a closure theory lens to Abbate allows for a more structural understanding of her work. Abbate's history foregrounds "the bold and creative strategies" of women computing workers in an effort to acknowledge their own agency, and to illustrate how the history of computing is gendered. Her historiography focuses on restoring the agency to these women, so while she does discuss structural factors such as deskilled labour, her focus on the excellence of women in computing can reify discourses about excellence being required to do computing work (Miltner, 2018).

4.3.1. Working Practices

Since computer programming emerged as a job *during* wartime, the women working as programmers were not immediately pushed out of their positions. Unlike factory jobs, programming positions did not have men to reclaim them after the war. But many computing jobs simply vanished once the war ended. Because wartime computing work was considered a state secret, female wartime coders were not able to describe it as part of their work history when looking for new jobs (Hicks, 2017). In Canada, the ban on married women working for the government was reinstated.

During the 1950s, women continued to have a large presence in programming, such as in large businesses and scientific laboratories. They contributed to the development of programming languages (Gürer, 2002) and scientific computation (Currie Little, 1999). But traditional gender roles persisted in many ways: women still had to leave when they became pregnant (Abbate, 2012; Reinish, 1999), and women hit what they dubbed the "glass ceiling": a collective barring from managerial and senior positions (Currie Little, 1999).

Computing work was "not well understood in the early years" and indeed "[e]ven the men who built and oversaw the computers did not have a clear idea of what would be involved in using them". Unsurprisingly, management did not appreciate what programming entailed; as a result they frequently underestimated the training needs and skills required for the work. For example, new hires for ENIAC were not given any training in programming, but were instead trained in mathematics.

The men running computing labs did not anticipate that coding would actually be difficult (Ensmenger, 2010). It was expected to be clerical work; for example, the management structure of the ENIAC was that a male scientist worked as a planner, deciding what was to be computed, and a low-rank female "coder" would do the actual machine coding (Ensmenger, 2010). Managers viewed women as better employees for clerical work as they were "loyal and cheap" employees.

Managers often gave preference to university-educated applicants out of a sense that such applicants were more intelligent. It is worth noting that there were large class and race barriers to higher education during the 50s through 70s. While community colleges had a more diverse applicant body, and produced a large number of computing degrees, their alumni were often excluded in favour of university alumni without any computing background. For example, Hicks describes a case of a female computer operator being tasked in 1959 with training two new male hires who had no computing experience — after which these men were promoted and the woman demoted to an assistantship below them (Hicks, 2017).

Programming schools began opening in the late 1960s and were described in 1967 by the Economist as: "sprouting everywhere but many are not as good as they should be". These programming schools share many features with today's coding bootcamps. They attracted a more diverse crowd of students, and so had an usurpationary effect. However, these credentials were more likely to be questioned by managers than university degrees.

In this 1950–70 era, attrition was a common problem. For example, it was reported in 1969 that employers would lose 30% of new hires. Managers who tried different hiring and training practices still could not predict who succeeded in the job. This led managers to believe that that there was something "inherent" in whether somebody could program.

Managers, who had little understanding of the difficulty of programming, often placed unreasonable demands on computing workers (Ensmenger, 2010). Ordinarily agreeable employees developed a reputation for being asocial and aggressive, due to the pressures of the work. Management in turn began to assume that asocial behaviour was characteristic of the employees who stayed on the job. Personality tests became common in hiring, specifically selecting for asocial individuals.

It was known at the time that aptitude and personality tests, as well as degrees, were not accurate predictors of how well a job applicant would perform. Yet 68% of job candidates in 1966 were subjected to aptitude tests. These tests framed programming as a combination of math and logic ability.

4.3.2. Discursive Positioning: Software Engineering

Starting in the mid-50s, managers posted advertisements seeking a "logical man", aiming to distance programming from the "women's work" of hand calculations (Abbate, 2012). Male managers saw the reputation of computing as "women's work" as stigmatizing. To get more qualified job applicants and resources, they worked to improve the status of computing — which meant to make it more masculine.

Abbate chronicles how in the 50s, the term "software engineering" was coined and proliferated in an effort to improve the status of computing. Engineering was perceived as a higher status profession — and at the time was comprised of only 1.2% women.

Early software engineers describe the label of "engineer" as critical for improving their status. The select group of women who achieved this new label embraced the new title, as it gave them more respect in the workplace.

It may seem an innocuous phrase now, but the very term "software engineering" was provocative when first used. It represented an ideal which did not yet exist, and it was not obvious this was even an appropriate model for how to produce software (Abbate, 2012). Programmers of the time conceived of their work as an art or craft, rather than engineering. Similarly, the term "program" was adopted because it was an engineering term, supplanting the term "plan" from the hand calculation days of computing.

The creation of "software engineering" also continued a tradition of gendered division of labour. Similar to how women in WWII were "coders" and men were the "planners," now it was the men who were "software engineers" and "systems administrators," while job titles such as "operator," "coder," and "programmer" were held by more women. (Tijdens et al., 1997)

The image of computing as an engineering field was known in the 1960s to be less appealing to women than the view of computing as a mathematical, scientific, or business field. The demarcationary recasting of computing as engineering would have effects on the closure of computing for decades to come.

The creation of a new field — "software engineering" — was also used as an opportunity to re-establish who were the pioneers of computing. For example, early software engineering conferences did not invite the female computing experts of the time such as Grace Hopper and Jean Sammet. Awards were only given out for "engineering," not "programming." And even when a woman (Fran Allen) did receive such an award for software engineering, her physical prize was cuff-links and a tie clip (Abbate, 2012).

5. The Closure of Academic Computing

5.1. *Early Days of Computer Science*

In the 50s and 60s, CS was conducted through other departments, typically as a hobby or side-project (Ensmenger, 2010). In these early days of academic CS, programming stayed largely independent from industrial coding. The first CS classes were offered in the 60s, as the discipline struggled to assert itself (Campbell, 2006). By 1969, MIT had opened an undergraduate programme in CS, and the 70s marked the beginning of bachelor's degrees in CS offered typically through electrical engineering or mathematics (Ensmenger, 2010). While there were early CS departments in this era, it would not be until the 80s that CS programmes were commonly offered through their own departments.

From the start, CS seemed like a "grab bag of various topics" related to computers and attempts to define the discipline were inconsistent (Ensmenger, 2010). Was CS about information? Analysis? Algorithms? No consistent narrative was established, though algorithms eventually became dominant. Consistent with other conflict theoretic studies of science, it appears that CS is formed less around a common epistemic goal and more around social closure (Gieryn, 1983).

5.2. *Roberts: Cyclical Enrolment Booms*

Most histories of computing have focused on its formative years in the early 20th century, and its origins in the 19th century. Comparatively little has been written on the history of academic computing, in part due to how recently academic computing was established. In this section we will draw primarily on various works of Eric Roberts, who has written extensively on the history of enrolment patterns in computing.

Roberts' historiography is unlike Abbate's and Rossiter's in a number of ways: he is not a trained historian; he is not explicitly feminist; he comes from an *emic* perspective instead, drawing in part on his considerable experience as a computer science professor; he focuses on enrolment patterns and supplements them with a combination of secondary sources and insight as his own key informant; and he points out what he considers to be paradoxes in his history, but appears to lack the social theoretic tools to explain them. Adding a closure theoretic lens helps to fill in his explanatory gaps.

5.2.1. The Capacity Crisis of the 1980s

The early 1980s were also a boom-time for student enrolment in CS (Slonim, Scully, & McAllister, 2008b), which was linked to the rise of the personal computer. Personal computers had not been available until the late 70s. Prior to then, CS was hence only pertinent to academia, military, and business. We see this increase in Figure 1.

The establishment of CS departments coincided with the sexual revolution in North America. While CS was opening its doors, women were asserting their rights, including those to work and study. Many of the women who studied CS in this era arrived at the field from other areas, such as math, physics, electrical engineering, psychology, English, music, and linguistics (Gürer, 2002).

By the mid 80s, 35% of enrolled CS students were women. As seen in Figure 2, CS had a larger increase in female participation from the 1970s to 1980s than other STEM fields. Indeed, writings from the time describe CS as a "woman-friendly" science (Etzkowitz, Kemelgor, Neuschatz, Uzzi, & Alonzo, 1994).

Unfortunately, the nascent CS departments were ill-equipped to deal with surging student interest. To cope, departments began restricting admission to their majors. For example, Purdue restricted admission to its major in 1982, after which enrolments dropped to roughly one third of the previous number (E. Roberts, 2017). The University of Maryland enforced limitations on class size in 1982, and restricted admission to the major in 1984 (E. Roberts, 2017), which caused a similar drop in enrolments.

CS departments took a number of other steps to explicitly try to reduce enrolments, including adding new GPA requirements for taking particular courses, increasing the number of prerequisites, and retooling first-year CS as a weeder course (E. S. Roberts, Kassianidou, & Irani, 2002). These actions are examples of educational *gatekeeping*: exclusionary policy actions which affect how easy it is for students (or particular subgroups of students) to enter the "gate" to get an education.

In Roberts' words: "The imposition of GPA thresholds and other strategies to reduce enrolment led naturally to a change in how students perceived computer science. In the 1970s, students were welcomed eagerly into this new and exciting field. Around 1984, everything changed. Instead of welcoming students, departments began trying to push them away. Students got that message and concluded that they weren't wanted. Over the next few years, the idea that computer science was competitive and unwelcoming

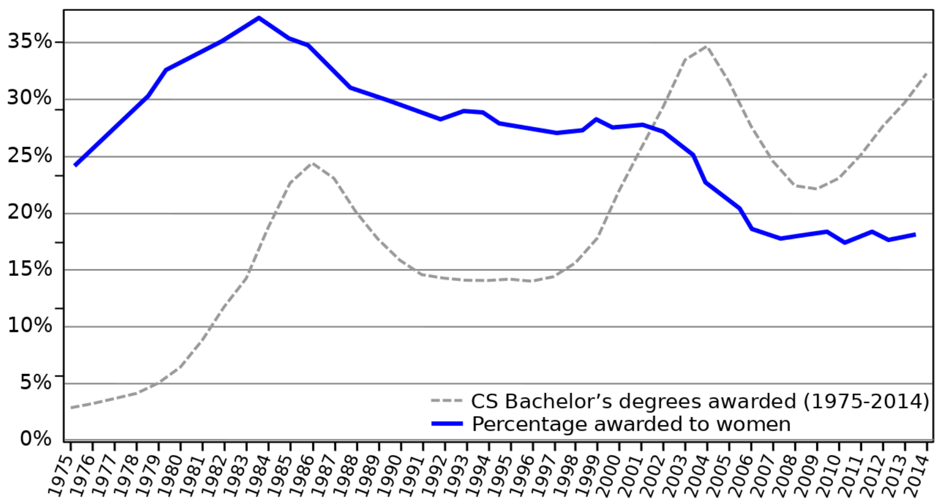

Figure 1. The grey dashed line indicates *total* CS degrees awarded, illustrating the "enrolment booms" of the late-1980s, dot-com, and present. Note that as this is degrees awarded, there is a lag between enrolling and graduating. The percentage of the degrees awarded to women is shown in blue. This figure is from (E. Roberts, 2017), using data from the National Center for Education Statistics.

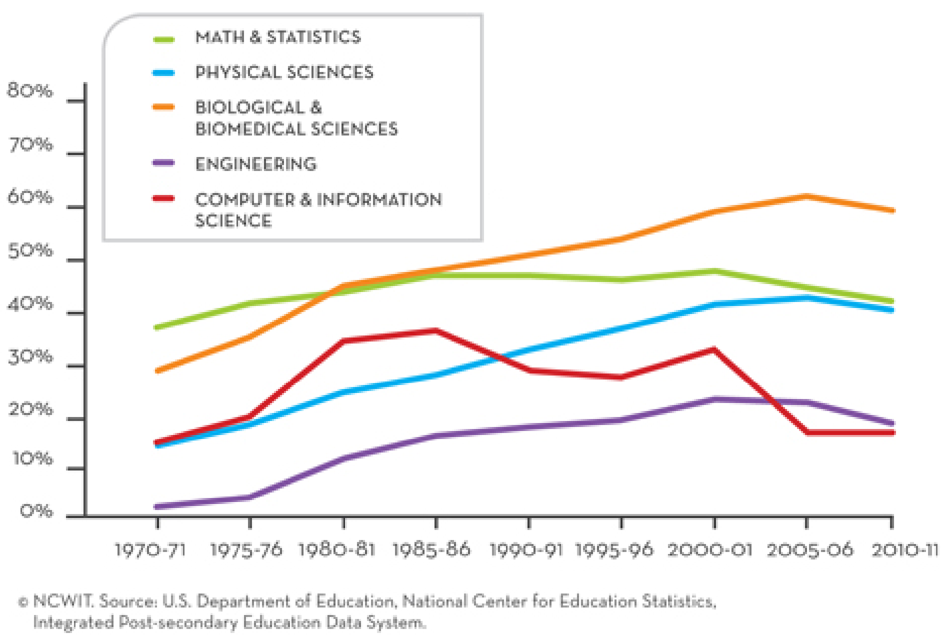

Figure 2. "Female percentage of select STEM undergraduate degree recipients: A longitudinal look" from Ashcraft et al. (2012)

became widespread and started to have an impact even at institutions that had not imposed limitations on the major." (E. Roberts, 2016)

Roberts notes that during this time period, CS departments hired more part-time/adjunct faculty and began hiring faculty from other disciplines, most of whom were from mathematics (E. Roberts, 2016). This contributed to the push to teach CS in a mathematically-focused manner rather than a multidisciplinary one. This had a gendered effect, since requiring mathematics backgrounds of students at a time when a disproportionate number of students who did not have math backgrounds were women. Furthermore, the retooling of first-year CS as a weeder course also resulted in a competitive, "chilly" atmosphere that disproportionately discouraged women.

The combination of gatekeeping policies and social changes to how CS was taught increased the social closure of the field. The closure disproportionately hurt the participation of women, as well as racial minorities (E. S. Roberts et al., 2002).

5.2.2. The Second Bubble: The Dot-Com Boom

The enrolment boom-and-bust story repeats itself again in the early 2000s: with the dot-com era came a new boom in CS majors, followed by a bust in student enrolment. The promise that a CS degree would lead to easy prosperity led to a resurgence in enrolments in the late 90s. And during this period we see a sharp decrease in the percentage of women, from around 27% to around 17% in Figure 1.

Some CS programmes began giving priority access to would-be majors who had taken high school CS, to filter applicants. This had a gendered effect, since high school CS was more male-dominated than the university population and women were more likely to first encounter CS at the university level.

The boom-time in the late 90s and early 00s led to a return of strict enrolment controls and a spree of hiring more CS faculty (Slonim et al., 2008b). Cukier's case study of how public universities in Ontario lobbied for more CS faculty gives us further insight to the occupational closure of computing. While most of the jobs in IT at the time were not based on a CS background, computing professionals successfully convinced policy makers that computer science (CS), computing engineering (CE) and electrical engineering (EE) were the only educational pathways into the IT sector, and therefore the only departments which should receive new tenure lines. The result was the exclusion of technological departments with more women, such as information systems (IS), business, and new media (Cukier, Yap, Holmes, & Rodrigues, 2009). This result was also a "win" for this demarcationary strategy.

CS programmes became increasingly marketed as being about mathematics and engineering, rather than applicable/relevant to business, languages, or social issues (Cukier et al., 2009). The need for "soft skills" in technology jobs were similarly downplayed (Cukier et al., 2009). Dryburgh found that women in this era had the perception that computing was about working with machines rather than people, and did not realize that computing work often had a social dimension (Dryburgh, 2000).

As a result of the above discursive shifts, women in technology who did not have CS/CE/EE backgrounds stopped identifying themselves as working in tech, but instead describing themselves as working in business, graphics, illustration, etc. (Cukier et al., 2009) As we saw in Section 4.3.2, this was not the first time the industry used the tactic of discursively positioning computing as an engineering discipline in order to improve access to resources and status, in turn closing off the "women's" paths into the field.

When the bubble burst, CS departments were left with a shortage of student interest. Some reports from the time describe it as a "crisis" in low student demand (e.g. (Slonim, Scully, & McAllister, 2008a)), and improving female representation was often cited as a way to improve the situation (e.g. (Slonim et al., 2008a)).

Roberts notes that after the dot-com bust, the IT industry became perceived as volatile and vulnerable to outsourcing, which dampened student interest for years to come (E. Roberts, 2016). Since many women — particularly women of colour — chose to major in CS as a way of climbing the social ladder and acquiring a reliable income (Varma, 2007b), the perceived volatility of a CS career had a gendered effect.

5.2.3. The Third Bubble: The Present

Enrolments did not recover again until the mid 2000s — and then kept rising (Slonim et al., 2008b). And while the *total* number of women in computing did eventually recover to the dot-com era numbers in the early 2010s, the *percentage* has not recovered (E. Roberts, 2016). While computing has become more popular, it appears to be much more so for men. At the time of writing, CS is facing its third enrolment boom, with enrolments now greater than the peak of the dot-com bubble (McGettrick & Timanovsky, 2012). Concerningly, the newest data indicates that while enrolments are going up, the percentage of women continues to shrink (Code.org, 2017).

More research is needed on female participation during the current enrolment boom. So far the research has been depressing: Patitsas et al. report that CS departments are not considering diversity when making policy decisions in response to the current enrolment boom (Patitsas, Craig, & Easterbrook, 2016), Barker et al. note that some departments are reducing or eliminating non-major service courses (Barker & Camp, 2015), and CRA's Generation CS report notes that departments which do consider diversity have higher female representation in their CS programmes (Computing Research Association, 2017).

Overall, a pattern of growing-but-cyclical enrolment emerges. Boom times lead to more students, then more enrolment controls. Bust times also result in disproportionately many women leaving the field, or not going in at all (Slonim et al., 2008b). While the *total number* of women does appear to recover after a bust, a much larger number of men enter the field; each boom has a greater total number of students than the previous boom. It remains to be seen how CS will respond to and be affected by the current enrolment boom.

6. Generations of Women in Computing

In this section we will discuss how the experiences of women in academic computing have changed since the emergence of academic computing in the 1960s. As documented by Etzkowitz et al. in a 1994 paper, women of different academic *generations* in STEM have had wildly different experiences in academia. In a study of 30 American academic science departments in biology, chemistry, physics, CS, and electrical engineering, Etzkowitz found stark and sometimes conflicting differences between the women of different generations in these departments (Etzkowitz et al., 1994).

The Etzkowitz et al. paper was published over 20 years ago, when the Second Generation was still growing. Women entering CS since the 00s have had a different experience of computing culture. To extend this history, we rely on Sturman's institutional ethnography of women in academic computing. While she did not use the term "generation" in her work, she examined the differences between the women who were students in the 1980s and the women who were students in the mid 2000s, focusing on the changes in social context and contrasting second- and third-wave feminism.

6.1. *The First Generation: women who entered in the 1960s and 70s*

The First Generation of women in a given STEM department faced a very different environment than subsequent generations. Unlike today's undergraduates entering classrooms with women as minorities, these women often entered classrooms with *no other women* (Etzkowitz et al., 1994). There were seldom other women in their field, and this continued into graduate school and faculty life. Such was the case faced by the majority of women who entered CS in the 60s and 70s, before CS was even an established discipline.

One senior female scientist in Etzkowitz et al.'s study described her cohort as such: *"The ones who did [science] were really tough cookies. Now it's easier to get in. At one time it wasn't even acceptable to start. So if you started back then you were tough to begin with."* The reality was that women with low self-efficacy simply did not go into that given STEM field; only the most dedicated stuck it out. This environment led these women to expect that women had to be better than men in order to succeed (Etzkowitz et al., 1994). Women were underrecognized for their contributions (Rossiter, 1993), and when they were, they got "separate but not quite equal form[s] of recognition" (Reinish, 1999).

With few other women around, these women worked in a culture which expected them to *"accept the strictures of a workplace organized on the assumption of a social and emotional support structure provided to the male scientist by an unpaid full-time housewife"* (Etzkowitz et al., 1994). These women adopted lifestyles and approaches mimicking the traditional man, including a singular focus on career advancement. Marriage and children were secondary, if done at all.

6.2. *The Second Generation: women who entered in the 1980s and 90s*

Etzkowitz et al. found that the hiring of women faculty in a STEM department *"definitely changes the attitude of how male students react to women. They must take them seriously and this is positive"*. Explicit sexist behaviour, such as public sexual joking and stereotyping, decreases as a result. Etzkowitz et al. found that there is a critical threshold at which women *in a department* begin to be treated more fairly, and blatant discrimination becomes uncommon. This appears to be at around 15% women.

The women entering this environment (in the 1980s and 90s) had a different experience than the First Generation, who had had *no* female faculty when they were students. The Second Generation was particularly eager about these First Generation female faculty. They had high expectations about these female faculty, and wanted to learn things from them such as *"how to dress, how to act at conferences, what to do when somebody is curt to you"* (Etzkowitz et al., 1994).

While the First Generation was preoccupied with simply getting on in a man's world, being a *woman* in a man's world was a preoccupation for the Second Generation (Etzkowitz et al., 1994). These women were concerned about how many women there were in their programmes, hired as faculty, etc. Viewing science as only one part of their identity, these women also focused on how to balance career and family.

For Second Generation women, work-life balance was the key problem. Figuring out when to start a family, and seeking maternity and daycare support from their universities were priorities (Etzkowitz et al., 1994). As noted already, many left academia because they felt balancing both work and family care to be untenable. However, more recent studies have found that the decision-making is complex: women who are more satisfied with their jobs are more likely to make having both academia and a family work. Women who feel they are discriminated against at work and/or feel their promotion and tenure chances are unlikely are more likely to leave the job to look after their families (Glass, Sassler, Levitte, & Michelmore, 2013). To improve their work satisfaction and remedy their sense of isolation, these women began most of the "women in science"–type clubs and other usurpationary initiatives (Etzkowitz et al., 1994).

6.2.1. Second-wave Organizing

In 2005–6, Sturman conducted an institutional ethnography of the women-in-computing lunches at three Ontario universities. To historically situate her observations of the lunches, she interviewed faculty about the history of the lunches. They began in the 1980s; female CS graduate students had felt the need "to come together for communication and support" amidst a "chilly climate" in their departments.

For context, the 80s were a time when feminists were turning their attention to academia; women were organizing groups to draw attention to "women's issues" such as campus safety, sexual harassment, and workplace discrimination. These efforts were rooted in second-wave feminism.

The informal lunches and dinners in the 80s were "a student-initiated intervention to 'help people in the program'" (Sturman, 2009). As time went on, these female CS grad students became more activist. Some of these women went on to present a report to university officials, highlighting concerns about the "climate" for women in science. For example, for women in computer science, building and campus safety at night were an issue, as they often worked late in the computer labs.

These lunches are just one example of the grassroots efforts created by Second Generation women in the 1980s. The Systers mailing list was started in 1987 to create an online community for women in computing (Abbate, 2012). (Shortly thereafter, a "TechTalk" mailing list was created as part of a sexist backlash, to promote the "technical only, no women-specific aspects" of computing (Abbate, 2012).)

The Grace Hopper Celebration (GHC) of Women in Computing evolved out of these grassroots efforts, and was first held in 1992. GHC was created to be a high status technical conference to highlight the technical contributions of female computer scientists (Abbate, 2012). It began as an imagining of what a CS conference could be like, with child care on site and a cooperative atmosphere (Abbate, 2012).

GHC, Systers and the women's lunches are all examples of separatist usurpationary efforts by women in computing, to carve a place for women in the field. Typical of usurpationary efforts, they were all contested — sometimes by other women.

6.2.2. Conflicts Between First and Second Generation

Etzkowitz et al. observed that the different experiences between the first two Generations has led to a bifurcation of the women in their study's participating departments. When the Second Generation began most of the "women in science" clubs, lunches, celebrations, etc; some of the First Generation were leery of these organizations. "*Fear of stigmatization led some [women] to deny the existence of gender-related obstacles.*

Calling attention to difficulties overcome could lead to countercharges of special privileges received", devaluing their hard-fought achievements that often took significantly more work than the achievements of their male colleagues (Etzkowitz et al., 1994). Furthermore, "*frustrated by the emergence of women's issues, they regarded such concerns as indicative of a lack of commitment to science. They believed women's groups and programs [sic] to improve the condition of women harmed female scientists by making them appear 'different', and by implication less competent*" (Etzkowitz et al., 1994).

The ideal of "universal sisterhood" often fell flat in the interactions between the First and Second Generations. As one of Etzkowitz's First Generation participants described the Second Generation: *"They are just not taught to be competitive. They don't expect to win. The reason why I am successful is because I never felt this way."* Here we see the senior female scientist not only dismissing the younger generation as weak, but also distancing herself from them, in an act of dual closure.

Advising was another source of inter-generational conflict. One female graduate student in the study reported that it was harder as an advisee of a senior woman, due to her advisor's sink-or-swim attitude. Many of the First Generation were harder on their female advisees, feeling they had to be in order to "prepare them to meet the higher standards they would be held to as women" (Etzkowitz et al., 1994). Many of these stories are reminiscent of the examples of dual closure Witz documented of the second generation of female doctors in Britain: the senior women could be harsher on the younger women following in their footsteps than the men were (Witz, 2013).

6.3. *The Third Generation: women who entered in the 2000s and 2010s*

The Etzkowitz et al. paper was published over 20 years ago, when the Second Generation was still growing. Women entering CS since the 00s have had a different experience of computing culture. When we entered CS as an undergraduate in 2007, approximately 20% of the CS faculty at our alma mater were women, predominantly of the Second Generation. These women faculty had families. Diversity efforts were in place, such as a Women in CS club was (and still is) highly visible and active, as is their delegation to Grace Hopper, as well as scholarship and research opportunities designed for women in CS.

The early 00s marked an era of focus on increasing female participation in CS. Margolis and Fisher's influential *Unlocking the Clubhouse* was published in 2002; that year also marked a SIGCSE bulletin special edition highlighting research on women in computing (Cohoon, 2002; Gürer & Camp, 2002). In 2004, the National Center for Women & Information Technology (NCWIT) was chartered by the National Science Foundation (Patitsas, Craig, & Easterbrook, 2014), establishing a usurpationary network of previously isolated initiatives to improve gender diversity in the field.

6.3.1. The Formalization of Usurpationary Efforts

Sturman's institutional ethnography paints a very different picture of usurpationary efforts in the 2000s than what was seen in the 1980s.

The Women in Computing (WIC) lunches of the 2000s at the universities she studied had become formal gatherings, organized by CS departments rather than grassroots affairs (Sturman, 2009). Their goal had become improving numeric equality in CS, rather than advocating for the women already in the field.

Per Sturman, the faculty who organized the lunches intended for the lunches to create community for the female students. This goal was based on the faculty member's own experience of being one of the few women and bonding with the other women.

Ironically, these formalized lunches could have a negative effect on the students. They felt they had "nothing in common" with the other women at these lunches: *"there was no inherent commonality to the group based on gender, other than the fact that they were all women, and all together 'in the same room'. .... The diversity of their countries of origin, their educational backgrounds, their family responsibilities (or not) and many other aspects of their lives often made the idea of shared 'experience' seem alien to them."* (Sturman, 2009) Further, the students viewed the lunches the as main (if not only) commitment of their department to gender equality.

Sturman described the 2000s-era WIC lunches and Grace Hopper Celebration as a merging of the "North American Second Wave liberal feminist belief in 'universal sisterhood'" and neoliberalism. The lunches and GHC were presented to female students as a place for networking for their careers. Instead of being a premiere technical conference, GHC had evolved into a glorified job fair where tech companies could recruit more women to their ranks to "prove" their commitment to women.

For the female students who attended GHC, the main pull was networking with other women in the field, and with the large tech companies who recruit there. The older generation's goals of universal sisterhood were not shared with the young: "there was little or no identification with networking as a method of establishing solidarity or group affiliation as 'women'; most understood the practice as instrumental in the establishment of professional contacts, but little more." (Sturman, 2009)

As CS departments embraced numerical goals for diversity, the female students felt they were used by their institutions to meet institutional diversity goals. Sturman describes: *"they felt subjectified as 'women in computing' for special interest from the university but with little direct power in effecting institution change where gender inequity was identified".* (Sturman, 2009)

6.3.2. Conflicts Between Second and Third Generation

Similar to how Etzkowitz et al. documented tensions between First and Second Generation women in science, Sturman's ethnography provides numerous examples of tensions between the Second and Third Wave/Generation women in computing. As we saw in the previous section, Third Generation women could sometimes feel alienated by the Second Generation's usurpationary efforts.

The Third Generation is in some ways removed from the overt, explicit sexism that the First Generation experienced. Insidiously, many Third Generation women do not perceive any gender-based biases against them, and are unwilling to take action on what they consider a "problem of the past" (Zuk & O'Rourke, 2012).

Concerningly, one issue affecting younger women in CS is backlash for the women-in-CS initiatives. Even in the Margolis & Fisher study era, female students reported harassment that "you're only here because you're a girl" (Margolis & Fisher, 2003). The stigma of receiving preferential treatment in STEM has been documented as decreasing self-efficacy for its recipients (Van den Brink & Stobbe, 2013), decreasing the self-perceived competence of its recipients (Heilman, Block, & Stathatos, 1997), and potentially causing stereotype threat for its recipients (Heilman & Alcott, 2001; Steele, 1997). This stigma undermines usurpationary efforts by minority groups. Sturman's participants described ambivalence toward diversity efforts, and a sense of needing to be careful about associating themselves with them (Sturman, 2009).

Conflicts can also arise between the second-wave feminism of the Second Generation and the third-wave feminism of the Third Generation. One illustrative example from Sturman's ethnography of GHC describes a heated session titled "Female Friendly Education: Increasing Participation or Watering Down?". One of the panelists, Sue Rosser, had coined the term "female friendly science" to signify a new approach to university science education which would take into account how science is gendered. This was poorly received by the Third-Generation women in the room. The Second-Generation panelists questioned why "third-wave" (their term) feminists and younger CS women in general responded negatively to the term "female friendly". To the Third-Generation women, the positioning of "female friendly" marked them as gendered subjects, less competent at computing, and Othered. '

An inherent tension between second- and third-wave feminism lies in the understanding of essentialism. A second-wave feminist usurpationary tactic has been to try to position femininity in a positive light, to counteract sexist discourses that present femininity negatively. Sturman observed how WIC events would use essentialist discourse to argue that femininity and CS are compatible.

The downside of essentialism is that it reduces all women to being the same. Psychology research has indicated this can reinforce sexist attitudes, even when the essentialism is considered positive (e.g., "women are better at communication") (Hammond et al., 2013). Further, women who don't fit the feminine ideal are left out of this usurpationary approach. Third-wave feminism hence takes an anti-essentialist approach: instead of trying to improve the status of feminine traits, to question how gender is socially constructed and account for the diversity within the genders.

6.3.3. Dual Closure

Part of the disconnects between the Second and Third Generations comes from differing demographics. The Second Generation women depicted by Sturman and Abbate were predominantly white, heterosexual, cisgendered, abled, American/Canadian and middle-class. Since the 1980s, universities in the US and Canada have had increased representation of students who are non-white, international, mature, LGBTQ+, and disabled. The result is that Third Generation women are a more heterogeneous group than the previous generation.

Sturman discusses how queer women felt out of place at WIC events on work-life balance which come from an assumption of heteronormativity. She also documents how international students felt out of place when encountering cultural barriers to participation and rhetoric that they were not the "right" women to be in CS.

Nationalist discourses to improve gender diversity in American and Canadian computing in order to reduce immigration, fill technology jobs with Americans (or Canadians), and the like are commonly used in modern efforts to improve female participation in computing (Vogel, Santo, & Ching, 2017). These discourses communicate to female international students that they are not the correct women to be in computing (Sturman, 2009). Similarly, Sturman documented how the Grace Hopper Celebration consistently depicted only young white women in their promotional materials, reinforcing an image of what a woman in computer science should look like.

The result is dual closure of CS: in the usurpationary effort to increase the number of women in CS, women of dominant social groups exclude women of minority groups.

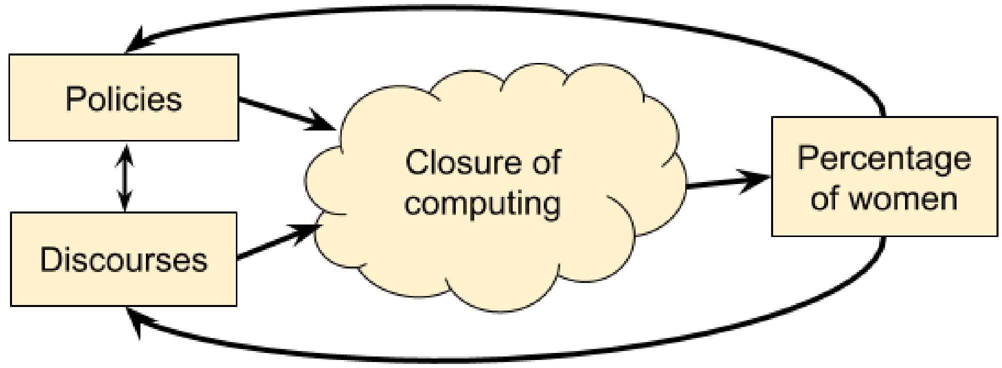

Figure 3. Illustration of our closure theoretic understanding of female representation in computing. Policies and discourses affect the closure of computing, which in turn affects female representation. Female representation can then affect policies and discourses: for example, high female representation in the 1950s led managers to use policies and discourses to try to increase the status of the field, in turn closing it and affecting female representation in turn. Low female representation has also been used to create policies at universities like Carnegie Mellon and Harvey Mudd to reduce the closure of computing and improve female representation.

7. Discussion

7.1. *The Big Picture*

What we see in the history of women in computing is that as the field has increased its social closure, the fewer women there have been in the field. This closure is changed through discourses and policies, and is illustrated in Figure 3.

Efforts to increase the status of computing, such as in the 1950s–70s, or to gain resources during university capacity crises, result in greater exclusion of women. In particular, discursively positioning computing as a form of engineering, and positioning more female-associated technological activities (e.g information science, digital media) as "not computer science", has contributed to the masculinization of the field.

Policies are also used to change the closure of the field. For example, using personality tests for hiring (during the 1950s–70s) and giving students with high school CS an advantage when applying to undergraduate CS majors are policies which have had gendered effects. But it can also be changed the other way: at Carnegie Mellon University, a usurpationary change in admissions policies played a significant role in increasing their female representation to 40% (Margolis & Fisher, 2003). Harvey Mudd College also has had similar success, through creating multiple entry points to their CS programme, offering research experiences to undergraduates, and giving female students the opportunity to attend the Grace Hopper Celebration (Alvarado, Dodds, & Libeskind-Hadas, 2012).

Women in computing have used a number of usurpationary tactics to establish themselves in the field. In the early history of computing, aligning with patriarchal nationalist discourses proved successful for white high/middle-class women. For example, 19th century activists argued that an education in science and mathematics would make them better "wives and mothers" for the sake of their given nation. And WWII-era women argued that contributing to the war effort through computing would defend their nations while allowing the women to look after their children. While usurping patriarchal national discourses was successful for these women to enter computing, this tactic left out many other women, and played into otherwise hegemonic discourses.

Usurpationary efforts in academia have also been problematic. The First Generation of women in academic CS favoured discursively positioning themselves to downplay their gender, and to fit in as a "man". By embracing discourses of computer science being engineering and not IT, they could raise their own personal status — but at the same time, this plays into an exclusionary discourse that excludes other women.

The Second Generation women tended to favour a separatist approach, creating communities for women in the field (e.g. Grace Hopper, informal lunches) and asserting that one can be both a woman an a computer scientist. But in an effort to show that one can be both feminine and a computer scientist, these spaces promote a discursive image of a woman in computing as white, native-born, abled, cissexual, heterosexual, and ultra-feminine — in turn excluding women who do not fit this norm. Hopefully the intersectional feminisms of the Third Generation will lead to new usurpationary discourses which are not also exclusionary.

7.2. *Limitations*

The generations described in this paper are based around common lived experiences. There are no clear-cut boundaries between them; some women may feel somewhere between two described generations, and the boundaries between generations may differ from one institution to another.

There is an inherent survivorship bias in studying which women make it in computing without comparing to the women who did not remain in the field. Unfortunately, the historical sources on hand are all subject to this limitation. As the adage goes, history is written by the victors.

An important reason for why we use social theory in this work is to provide triangulation between the historical evidence and the existing sociological literature. Since no single research method is perfect, we need theory to link works together. While we used closure theory to present this history, it is worth taking a second look at the other social theories commonly used to explain gendered work. With respect to neoclassical human capital theory, we do see that women were hired in higher numbers during wartime, which were times of labour shortage. But IT has had a perpetual skilled labour shortage, and men were hired during peacetime labour shortages when the field was more concerned with improving its status.

With regard to occupational segregation theory, we do see horizontal segregation consistently. Nothing in this history directly refutes the theory. Occupational closure theory, however, can explain phenomena that are not considered by occupational segregation theory, such as conflict between groups of women computer scientists, or the gendered effects of enrolment booms in university CS.

The literature used in this review focuses on the experiences of dominant-group women at large institutions (e.g. large universities, large companies, militaries) in the US/Canada. As such, this paper does not provide an account of the history of women in computing who are not in dominant groups (e.g. non-white, disabled, LGBTQ+). Unfortunately, more research is needed to increase our collective understanding of how CS excludes groups other than women, and the intersections thereof.

There are some parallels between the history of women in the US/Canada from the 19th century to the 1950s and what we see in some developing countries how. We will describe these in the next subsection as a form of triangulation.

7.3. *Non-Western Computing*

We see parallels between the history of women in CS and in the research on why women are better represented in CS outside the West. This corroborates using our historical understanding of women in CS to study women in CS more generally. Non-Western countries are particularly useful for us to look at to see what generalizes across different cultures and societies, in the spirit of Harding's strong objectivity (Harding, 1992).

CS is currently female-dominated or at gender-parity in places such as the Middle-East, Eastern Europe, and South-East Asia (Galpin, 2002). A 1994 study by Barinaga set out to explain the cross-cultural differences in female participation in STEM, which found five positive factors. Galpin replicated Barinaga's findings for the CS context. Barinaga's factors are:

(1) More women are present in countries with **recently developed science capabilities**. The academic culture is relatively unentrenched, and no "old boys network" dominates. When CS was new — and less closed — we saw more women in the field. This was true both in industry (female computers) and in academia (the 80s).
(2) More women become scientists in a culture where **science is perceived as a low status career**. It is established in sociology that the lower the status and pay an occupation, the more likely it is that women will be found there. When CS meant being a "computer" or a lowly "coder," women played these roles. When CS increased its status, such as during the dot-com boom, the percentage of women entering CS decreased.
(3) For a given culture, if a woman of high class has higher social standing than a man of low class, we see more women in science. **Social hierarchy** matters — and not just gender and class, but also race, nationality, sexuality, and disability. Women in CS are more likely to be from high-SES backgrounds (Margolis & Fisher, 2003). Black and Latina women are particularly underrepresented (Margolis, 2008). Dual closure hence plays a role in which women study CS.
(4) Women are more commonly seen in countries where math, biology, chemistry, and physics are all compulsory in secondary school. The policy choice of making STEM compulsory reflects a cultural value that anybody can learn math and science (i.e. a Dweckian growth mindset). In countries like the US where science is not mandatory in secondary school, science is closed to the "usual suspects." Women are more likely to study science — and computer science specifically (Margolis & Fisher, 2003) — when they come from **cultures that promote a growth mindset**.
(5) Female science participation is higher in **cultures where childcare is a shared responsibility**: between father and mother, the extended family, and society at large.

Moving onto other cross-cultural studies, two non-Western countries have been investigated specifically on why they have more women: India and Malaysia.

Women make up 42% of computer science students in India (Varma & Kapur, 2015). The literature on why women are better represented in India points to computing being seen there more as clerical work (Patel & Parmentier, 2005); a demand for educated wives/mothers amongst urban high-SES groups (Patel & Parmentier, 2005; Varma & Kapur, 2015); vertical segregation within Indian IT (Patel & Parmentier, 2005); and usurpationary efforts by women to find reliable, interesting and empowering work (Varma & Kapur, 2015).

In Malaysia, women make up 65% of computer science students. Mellström attributes the greater female participation there to the fact that computing is seen as a clerical "desk job", vertical segregation in the industrial sector, women's usupationary efforts to contribute to Malaysian nation-building, and the dual closure of ethnic Malays (and hence Malay women) having preferential access to a university education over Malaysian students of Chinese or Indian descent (Mellström, 2009).

These are both similar to the history of computing in the late 19th century and early 20th century, where computing was female-dominated. Computing was seen as a clerical job at a time of high vertical segregation; this overlapped with a push for high-SES women to be educated to be "better wives and mothers," and women signing up for computing jobs for their own empowerment or to contribute to war efforts.

7.4. *Implications for Educators*

For CS educators seeking to improve the gender balance of their classrooms and programmes, learning about this history is useful knowledge. First, it lets you know that the gender balance in CS is not fixed; we can change it. But it's also not guaranteed to improve on its own.

The gendered history of CS is different from other STEM fields, so lessons and trends in those fields may not transfer to computing. The gender ratio in computing has gone both up and down multiple times in its history. For us to change this system, we need to understand the dynamics — the history — of this system.

To many educators, the gendering of CS feels like it is something outside their control. Our society presents computer scientists as male nerds, and this turns off those who don't fit the image. Understanding the gendering of CS in terms of closure not only identifies the mechanisms by which CS is gendered. As it turns out, educators have the power to influence these mechanisms: discourses and policies.

One thing professors can do is to participate in university admissions committees and ensure that the pathways into a CS major are accessible to groups more likely to contain women, such as transfer students and double-majors with subjects such as cognitive science. This is especially important during times of high enrolment. Research indicates that CS departments that consider diversity in their policy-making are more likely to have a better gender balance of students (Computing Research Association, 2017). In department meetings, routinely ask: how will this affect diversity?

Educators also influence discourses. An introductory class in computing is where many students receive messages about who is and is not a computer scientist. If you encourage a growth mindset rather than a fixed "Geek Gene" view of who will do well, you open your learning environment up to more students. If you dismiss areas such as information science, human-computer interaction, computational media and cognitive science as "not computer science" you are contributing to the closure of the field. Presenting CS as an interdisciplinary or multidisciplinary field changes the picture.

For faculty who organize events for women students, it is important to realize that these students may have differing feminisms and lived experiences. Rather than assuming that you know what is best for them, encourage students to self-organize and to participate in university policy processes. Encourage students to learn about how CS is gendered and how this has changed. This can empower your students to realize it *can* be changed. It can also lead female students to realize that when they encounter sexism in the field, it is not them that is at fault, but rather the social system.

8. Conclusions

Across history and geography, trends arise in when and where women play a larger role in computing. When and where computing is discursively presented as a clerical desk job, we see more women; and when and where it is discursively presented as engineering, we see more men. Closure operates on the group level: it is not about excluding or including individual women/men, but rather excluding/including groups that may happen to be more women or more men.

Another trend is vertical segregation: e.g., a man is the "planner" and the woman is the "coder," or the man is the "software engineer" and the woman is the "programmer." In Witz's terminology, this is an example of demarcation. We see more women in low-status IT-related positions, and their work is often demarcated from what is considered "computer science." In the dot-com era, more-feminine areas such as information systems and computational media were discursively positioned as "not CS," reflecting the historical trend of more-feminized tech work being deskilled and undervalued.

The other mechanism through which we see the historico-geographical trends vary is through policies. Hiring policies in industry and admissions policies in education have large effects on who enters computing. Historically, we see a pattern that during wartime (e.g., US civil war, WWI, WWII) more women work in computational jobs. In academia, we see another pattern: when computing is popular and tied to economic prosperity, enrolments in CS surge — and the percentage of women decreases.

This is, however, not fate: at universities such as Carnegie Mellon and Harvey Mudd, low female participation was successfully used to motivate policy and discursive changes to reverse the closure of computing.

Over time, women in computing have used a number of tactics to improve how included women are in the field. However, tactics are not always perfect. Discursive tactics designed to show how women are "just as hardcore as the guys" or that "computing is a good career for mothers" can be double-edged swords. These discourses can and have been successfully used to further the acceptance of the women who wield them, but at the same time contribute to the overall closure of the field. Discourses that promote a growth mindset and an interdisciplinary view of computing have greater potential to open the field to more students.

The gendering of computing is a social phenomenon with a deep history, and changing it without considering its history is unlikely to succeed. Twice the field has had enrolment booms where the percentage of women in undergraduate CS dropped, and now we face a third enrolment boom. Will we learn from history this time?

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Chapter 6

Are CS Grades Bimodal? Examining A Common Discourse in Computing

In this chapter, I present a paper which explores the common notion amongst CS educators that their grade distributions are "bimodal", and how this notion is tied to the discourse that you need a "geek gene" to succeed in computing [155]. In the previous chapter, we saw that discourses have been used in the closure of computer science. One discourse that has been identified as contributing to the exclusion of women in computer science is the notion that you need some innate ability or "brilliance" to succeed in the field [46, 136].

6.1 The Brilliance Discourse

The notion that you need an innate ability to succeed is not unique to computer science [146]. Indeed, the notion goes by numerous names: science education resarchers will often call it the "brilliance" discourse, those working with Dweck's work will talk about it terms of fixed mindset, in physics education research it is called the "genius" discourse, in CS education the "Geek Gene Hypothesis" is more common and is what I use in my paper.

A study of academic fields found that how strongly the brilliance discourse is espoused is predictive of how strongly male-dominated the field is [128]. Similarly, the frequency of the words "brilliant" and "genius" in the open-ended portions of student evaluations of university teaching predicts the representation of both women and African Americans across academic fields.

The image our society constructs of what a "genius" looks like is highly gendered and racialized, and affects our biases and expectations of who is a "genius". There is a long history of scientists defining intelligence in a gendered and racialized way, and creating biased measures of intelligence to uphold social hierarchies [86]. Because women and racial minorities are excluded from this social imagitation of "genius", they are more likely to feel out of place in situations where genius is expected of them.

The brilliance discourse has been found to play a gendered role in academic hiring [199, 200]. It also plays a gendered role in how much parents and teachers encourage girls to study math [195]. Furthermore, exposure to messages about brilliance leads women (and not men) to expect they would not belong in STEM, and reduces their interest in STEM careers [24]. In short, the brilliance discourse is a potent one in the exclusionary closure of male-dominated fields.

6.2 Strategic Positivism

One of the reasons I wrote this paper was because Ahadi and Lister [3] had already made the central argument I make (i.e. perception of bimodality is just a reflection of the brilliance discourse), but their argument had not really been taken up by the CS education research community. While their argument had been made on theoretical grounds, my experience was that the CS education community is more inclined to listen to quantitative positivist research.

6.2.1 What is strategic positivism?

I would describe this paper as an act of *strategic positivism*. For one to understand the term "strategic positivism", one may find it useful for me to first discuss what is meant by "positivism".

The term "positivism" has been used in many different ways over the years. In his classic 1982 books, Halfpenny documents twelve distinct epistemic schools of thought that have been called "positivism" [101]. But when I talk about positivism in this section, I am not truly talking about a coherent epistemology but rather a social group: specifically, a social group that favours reductionist, quantitative approaches to social scientific research, and expects that there are unique "right" answers to social problems. People in this group may come from different (post)-positivist epistemologies.

The term "strategic positivism" is used most commonly by critical theoretic and postmodern researchers, and refers to research or rhetoric designed to speak or appeal to dogmatic positivists [221]. In many social scientific communities, non-positivists and their work are marginalized; as Fields describes, strategic positivism is "using sanctioned methods of producing knowledge (with an emphasis on quantitative approaches), deployed via postmodern sensibilities of multiple meanings in the service of politically progressive aims" [70]. Latour notes that term intentionally is meant to conjure Spivak's notion of "strategic essentialism" [124], and has even been used by Spivak herself (in [183]).

6.2.2 Impact

Consistent with strategic positivism, I tested a hypothesis that was theoretically proposed but not empirically assessed, knowing that whatever my results would be would spark a discussion in the CER community. The reception was much stronger than I had expected: I won the John Henry Award at ICER that year, my paper made the front page of Hacker News, and even a conventional newspaper wrote a story on my findings.

This paper has been an uncomfortable reminder for me of the need for my research to make sense to positivists in order to have impact. It is known that CS educators are skeptical consumers of CS education research and prefer the research they find congruent with their own context [13]. While my intellectual journey has led me to many wonderful and powerful social theories, if I cannot reach and convince positivists of my findings, my work will join the collection of poorly-known but rigorous critical sociological treatments of gender issues such as those of Sturman, Dryburgh and Tijdens.

6.3 Post-Publication Notes

Since writing this paper in 2016, I have learned more about statistics. For a paper about how people don't understand statistics, I make an embarrassing number of statistical errors myself. Reading Goodman's "A Dirty Dozen: Twelve *P*-Value Misconceptions" [85] was a humbling experience; the paper reflects a number of the common misconceptions that Goodman indicated. Specifically:

- Misconception 1: If P = .05, the null hypothesis has only a 5% chance of being true
- Misconception 6: P = .05 means that we have observed data that would occur only 5% of the time under the null hypothesis.
- Misconception 9: P =.05 means that if you reject the null hypothesis, the probability of a type I error is only 5%.
- Misconception 10: With a P = .05 threshold for significance, the chance of a type I error will be 5%.

While my misconceptions do not change the ultimate findings, I would describe my data and analysis differently were I to write the paper today! I also would improve the way I describe my statisitcs — making it clear when I talk about samples, probability distribution functions, etc. Since publishing the paper it has become clear that I needed to explain the statistics in more depth for my audience.

A last change I would make to the paper would be to amend my sentence "Indeed, Porter et al. recently found that performance on early assessments in CS1 correlate highly with final grades, indicating that surprisingly little learning goes on in CS1", which is a misrepresentation of Porter et al.'s work. They found that students who performed well early in the term also went on to be the top-scoring students on the final, and vice versa. This finding does not mean that no learning happens, but rather that the ordering of students by performance is surprisingly fixed.

6.3.1 Replicability

Reinforcing my finding that bimodal grade distributions appear to be uncommon, and that most CS grades are normal, is the fact that my analysis has since been replicated. Basnet et al. replicated my grade distribution analysis at a four-year southwestern university in the United States for the period 2014-2017 [17], and found that 90% of the grade distributions were unimodal, and there was no evidence that any of the classes had bimodal grade distributions.

I have published the code used for my grades analysis at `https://github.com/patitsas/bimodality` for others to replicate my work.

Evidence That Computer Science Grades Are Not Bimodal

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ABSTRACT

Although it has never been rigourously demonstrated, there is a common belief that CS grades are bimodal. We statistically analyzed 778 distributions of final course grades from a large research university, and found only 5.8% of the distributions passed tests of multimodality. We then devised a psychology experiment to understand why CS educators believe their grades to be bimodal. We showed 53 CS professors a series of histograms displaying ambiguous distributions and asked them to categorize the distributions. A random half of participants were primed to think about the fact that CS grades are commonly thought to be bimodal; these participants were more likely to label ambiguous distributions as "bimodal". Participants were also more likely to label distributions as bimodal if they believed that some students are innately predisposed to do better at CS. These results suggest that bimodal grades are instructional folklore in CS, caused by confirmation bias and instructor beliefs about their students.

1. INTRODUCTION

It is a prevailing belief in the computer science education community that CS grades are bimodal, and much time has been spent speculating and exploring why that could be (for a review, see [1]). But these discussions do not include statistical testing of whether the CS grades are bimodal in the first place.

From what we've seen, people take a quick visual look at their grade distributions, and then if they see two peaks, they say it's bimodal. But eyeballing a distribution is unreliable; for example, if you expect the data to have a certain distribution, you're more likely to see it.

Anecdotally, we've seen new instructors and TAs (and students) shown histograms of grades and told the grades were "bimodal." The bimodality perception hence becomes an organizational belief, and those who enter the community of practice of CS educators are taught this belief. Every community of practice has a knowledge base of beliefs that inform their practice [13], and these beliefs may or may not be based on empirical evidence.

1.1 Explanations of Bimodality

A number of explanations have been presented for why CS grades are bimodal, all of which begin with the assumption that this is the case.

1.1.1 *Prior Experience*

A bimodal distribution generally indicates that two distinct populations have been sampled together [5]. One explanation for bimodal grades is that CS1 classes have two populations of students: those with experience, and those without it [1].

High school CS is not common in many countries, and so students enter university CS with a range of prior experience. However, this explanation fits students into two bins. Prior experience is not as simple as "have it" vs. not – there is a large range on how much prior experience students can have programming, and practice with non-programming languages like HTML/CSS could also be beneficial [21].

1.1.2 *Learning Edge Momentum, Stumbling Points, and Threshold Concepts*

One family of explanations could be summarized as that some CS concepts are more difficult for students to learn, and if they miss these concepts, they fall behind while their peers advance ahead of them [1]. Because CS1 as it is typically taught builds on itself heavily, once a student falls behind, they continue to fall further and further behind [1].

One might think of this explanation as a variant of the prior experience explanation, where the students who succeed have better study skills, and those who fall behind do not.

1.1.3 *The Geek Gene Hypothesis*

Some would instead argue that the two populations in CS1 classes are those who have some "natural talent," giftedness, or predisposition to succeed at computing. Guzdial has referred to this belief as the "Geek Gene Hypothesis" in his writing [6].

This belief appears to be quite prevalent. In a survey of CS faculty, Lewis found that 77% of them strongly disagree with the statement "Nearly everyone is capable of succeeding in the computer science curriculum if they work at it." [15].

However, there seems to be little evidence that there is indeed a "Geek Gene", and that plenty of evidence that effective pedagogy allows for all students to succeed [8].

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1.1.4 Lousy Assessment

Another line of explanation implicates instructors' assessment tools as the source of bimodally distributed grades [33, 23]. A common trend on CS exams is to ask a series of long-answer coding questions. Zingaro et al. found that these questions are coarse in terms of the information given to instructors: students either put all the pieces together, or fail to. Instructors do not adequately identify when a student has partial understanding nor quantify how much understanding this student has of a concept.

As an alternative, Zingaro et al. experimentally compared using short answer questions which build upon each other to having one isomorphic long-answer question. When the different conceptual parts of the question were broken up, the resulting grades were normally distributed, whereas the long-answer questions led to grades that the authors described as bimodal [33].

1.1.5 Or perhaps CS grades are not bimodal?

A competing view of CS grades argued by Lister is that the grades are not, in fact, bimodal [17]. Lister observed that CS grades distributions are generally noisy, and in line with what statisticians would accept as normally distributed. Lister argued that the perception of bimodal grades results from instructors' beliefs in the Geek Gene Hypothesis, and hence see bimodality where there is none [17]. Lister's argument was theoretical, and based on statistical theory; in our paper we will test his argument by statistically analysing real world grades distributions.

2. WHAT IS A BIMODAL DISTRIBUTION?

To properly tackle the question of "are CS grades bimodal?", we should first clearly establish what bimodality means.

Most standard continuous probability distributions have a mean, a median, a mode, and some measure of the distribution's width (variance). Standard distributions most people might be familiar with include the normal (Gaussian), Pareto, Poisson, Cauchy, Student's t, and logistic distributions. When we plot them with a histogram, we see what's called their probability density.

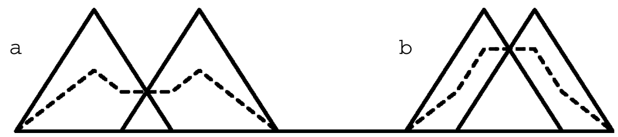
All of these distributions have a single mode, and have a probability density that can be modelled with a function that has a single term. For example, the normal distribution's PDF is:

$$f(x) = ae^{-\frac{(x-b)^2}{2c^2}}$$

In this function, a represents the height of the curve's peak, b is the position of the centre of the peak, and c represents the width of the curve [31].

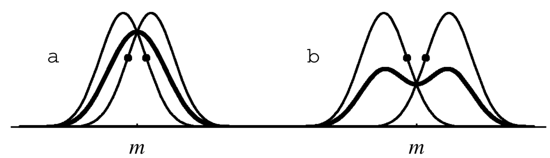
In contrast, a bimodal distribution has two *distinct* modes. A 'multimodal' distribution is any distribution with multiple distinct modes (two or more).

For an example, consider these examples from [28]. Both are created by the equal mixture of two triangular distributions (solid lines). The sums are shown with dashed lines:



As we can see, when the two sub-distributions are far away (example **a**), we get a distribution with two peaks. But when the two sub-distributions are close together (example **b**), they add together to form a plateau, with a single peak. Example a is considered bimodal; example **b** is not.

The same can be seen for normal distributions (also from [28]):



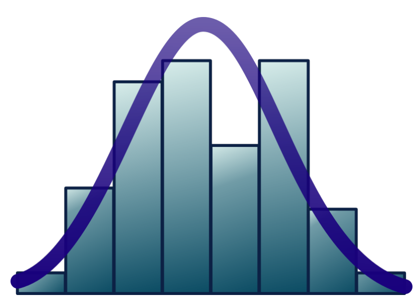
For a distribution to be bimodal, the sub-distributions can't overlap too much. As shown in [28], for the two distributions to be sufficiently far apart, the distance between the means of the two distributions needs to exceed 2σ. This, however, assumes the two distributions have the same variance.

More formally, if the two sub-distributions do not have the same variance, then for their sum to be bimodal, the following must hold [30]:

$$2^{\frac{1}{2}} \frac{|\mu_1 - \mu_2|}{\sqrt{(\sigma_1^2 + \sigma_2^2)}} > 2$$

2.1 Real World Data

Consider this histogram of sepal widths for the Iris species *versicolor*, taken from the Wikipedia page on "normal distribution" [31]:



These data have two peaks, but it is considered a normal distribution. If we were to try and model these data as the mixture of two normal distributions, the two sub-distributions would be too close together to produce two distinct peaks. The simplest way to model these data is as a normal distribution.

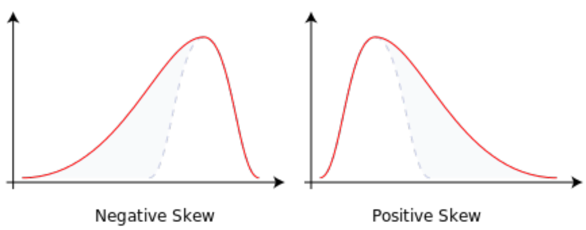
Finally, it must be stressed that what we see in a histogram is a result of how we bin the data. It is possible to bin these data in a way which do not have two 'peaks' (for example, using larger intervals for the bins, or shifting the intervals).

2.2 Skewness and Kurtosis

By definition, a normal distribution is symmetric around its mode (which is also its mean and median). However, many real world data which produce a bell curve when graphed as a histogram do not fit these properties.

2.2.1 Skewness

Skewness is a measure of how asymmetric the data are. A distribution with a skewness of zero is perfectly symmetric. In comparison, a distribution with a negative skewness will have a longer 'tail' on the left side than on the right side; the opposite is true of positive skewness [32]:

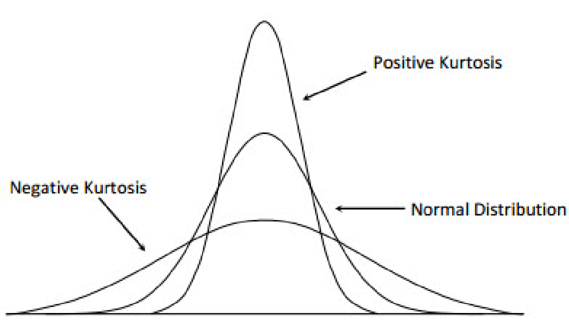


One may expect grades distributions to be skewed. One cause of skewness is the ceiling effect: if students are performing well (and this is normally distributed), and we set a maximum grade of 100%, this will cause the students at the top of the class to be bunched together.

By convention, if the absolute value of the skewness is greater than 1, a distribution is considered highly skewed; an absolute value of skewness between 0.5 and 1 is considered moderately skewed; less than 0.5 is considered approximately symmetric [32].

2.2.2 Kurtosis

Kurtosis is a measure of how 'tailed' the data is. A distribution with high kurtosis has a sharp peak and short tails. A distribution with low/negative kurtosis has a low peak and long tails. The normal distribution has a kurtosis of 3. A distribution with a kurtosis greater than this cannot be bimodal [30].



If you look back at the illustration of adding two normal distributions together, for the bimodal example, the distribution winds up being rather spread out horizontally. That distribution has low kurtosis. Indeed, for a distribution to be spread out far enough horizontally to allow for multimodality, it necessarily will have low kurtosis.

3. STUDY 1: STATISTICAL ANALYSIS OF GRADES

Are CS grades bimodal, or unimodal? To test this, we acquired the final grades distributions for every undergraduate CS class at the University of British Columbia (UBC), from 1996 to 2013. This represents 778 different lecture sections, containing a total of 30,214 final grades (average class size: 75).

3.1 Testing for normality vs. bimodality

There are a number of ways to test whether some data are consistent with a particular statistical distribution.

One way is to fit your data to whatever formula describes that distribution. You can then eyeball whether your resulting curve matches the data, or you could look at the residuals, or even do a goodness-of-fit test.

Another is to use a pre-established statistical test which will allow you to reject/accept a null hypothesis on the nature of your data. We used this approach, for the ease of checking hundreds of different distributions and comparing them.

There are a large variety of tests for whether a distribution is normal, such as Anderson-Darling and Pearson's chi-squared test. We chose Shapiro-Wilk, since it has been found to have the highest statistical power [25].

There are few tests for whether a distribution is bimodal. Most of them essentially work by trying to capture the difference in means in the two distributions that are in the bimodal model, and testing whether the means are sufficiently separate. We used Hartigan's Dip Test, because it was the only one available in GNU R at the time of analysis.

We also computed the kurtosis for every distribution due to the necessary (but not sufficient) condition of kurtosis < 3 for bimodality [30]. To minimize false positives, we only performed Hartigan's Dip Test on distributions where the kurtosis was less than 3.

We chose the standard alpha value of 0.05. Given that we performed thousands of statistical tests, false positives are inevitable – we expect 5% of our tests will yield a false positive.

3.2 Test results

3.2.1 Unimodality vs. Multimodality

Beginning with kurtosis, 323 of the 778 lecture sections had a kurtosis less than 3. This means that 455 (58%) of the classes were definitely not bimodal, and that at most 323 (42%) classes could be bimodal.

Next we applied Hartigan's Dip Test to the 323 classes which had a kurtosis less than 3. For this test, the null hypothesis is that the population is unimodal. As a result, if $p < \alpha$, then we may reject the null hypothesis and conclude we have a multimodal distribution. This was the case for 45 classes (13.9% of those tested, 5.8% of all the classes).

Of the 45 classes which were multimodal, 16 were 100-level classes (35%), 5 were 200-level (11%), 12 were 300-level (27%), and 12 were 400-level (27%). For comparison, in the full set of 778 classes, 171 were 100-level (22%), 165 were 200-level (21%), 243 were 300-level (31%), and 199 were 400-level (26%).

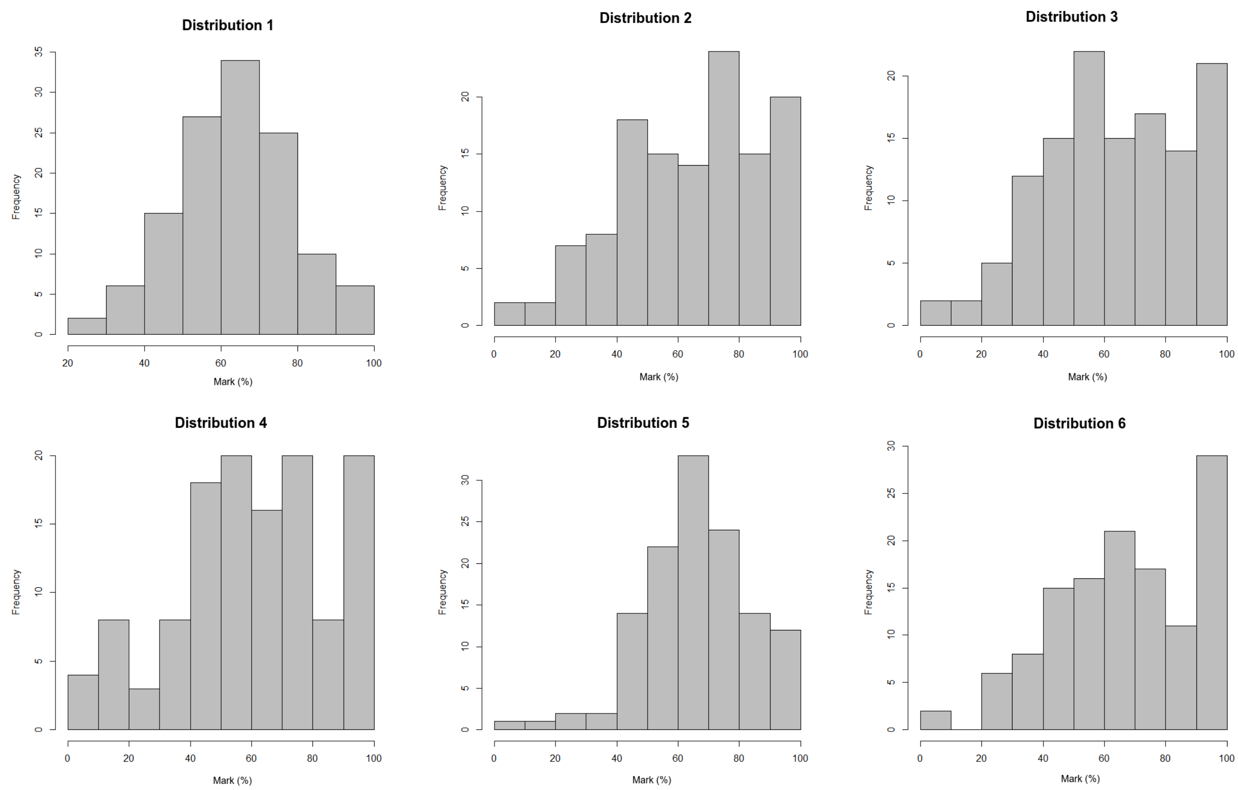


Figure 1: The six histograms shown to participants, all of which were generated using GNU R's `rnorm` function. A ceiling of 100% was used, which is most evident in Distribution 6. Each generated distribution had 100 points, and was generated with an average of 60 and standard deviation of 5.

1. Questions about how large their typical class was ("class-size") and how long they had been teaching ("years-experience").
2. A priming question: 'It is a commonly-held belief that CS grades distributions are bimodal. Do you find this to be the case in your teaching?' ("have-bimodal")
3. Questions on how often they look at their grades distributions:
   - 'When teaching, how often do you look at histograms of your students' grades? (This applies both to term work and final grades.)' ("look-histo")
   - 'How often do you look at how many students fall into each letter category (A, B, etc)? (This applies both to term work and final grades.)' ("look-letter")
4. Six histograms, all generated with GNU R's `rnorm`, shown in Figure 1. For each histogram, we asked two questions:
   - 'How often do you see the shape of [this distribution] in your classes?'
   - 'What sort of distribution would you describe [this distribution] as?'
5. Questions on the 'Geek Gene':
   - Nearly everyone is capable of succeeding in computer science if they work at it. ("all-succeed")
   - Some students are innately predisposed to do better at CS than others. ("innately-predisposed")

Table 1: The pages of the survey. Pages 2 and 5 were swapped for a random half of the participants. We chose the all-succeed question because it had been used in [16].

3.2.2 Normality

For the Shapiro-Wilk test, the null hypothesis is that the population is normally distributed. So, if $p < \alpha$, we can reject the null hypothesis and say the population is not normally distributed. This was the case for 106 classes.

44 of the 45 classes which were previously determined to be multimodal were among the 106 classes which the Shapiro-Wilk test indicated weren't normally distributed. In short, 13.6% of the classes aren't normally distributed, many of which are known to be multimodal.

For the 86.4% of classes where we failed to reject the null hypothesis, we can't guarantee that they are actually normal, because of type II error. Fortunately, we have a large sample size and good statistical power. We bootstrapped a likely beta value, providing an estimated false negative rate of 1.48%.

In short, an estimated 85.1% of the final grades in UBC's undergrad CS classes are normally distributed. If CS grades were typically bimodal, we would expect far more than 5.8% of classes to test as bimodal.

3.2.3 Skewness

While most of the distributions appear to be normally-distributed, it is worth noting that the average skewness of all the distributions was -0.33, ranging from -2.30 to 1.02. For just the distributions we'd determined to be normal, the average skewness was -0.13, ranging from -1.11 to 0.84. It is therefore likely that for many of the distributions which are unimodal but not normal, their non-normality is because they are too skewed to pass a test of normality. This may be a result of the ceiling effect in grade distributions.

3.3 Discussion

It is worth noting that we only examined final grades: our analysis did not include term grades.

As grades only came from one institution, one may wonder about the generalizability. We tried to get access to grades distributions from other institutions but generally found it difficult to gather the same scale of data. Analyzing five grades distributions from the University of Toronto, we found them to be normally-distributed.

While we can't assert that every university has the same grades distributions as UBC, the large scale of data both in numbers and time-span gives does give us a great deal of information. More work should be done to replicate our findings at other institutions.

What stood out for us is that at both UBC and UToronto, the CS faculty would routinely assert that their CS grades are bimodal – and we now had evidence to the contrary.

Our results support Lister's argument that CS grades are generally not bimodal, and that the perception of bimodality comes from instructors expecting their grades to be [17].

4. STUDY 2: HUMAN INTERPRETATION OF DISTRIBUTIONS

So if CS grades are rarely bimodal, why does the belief in bimodality persist? An insight came one day when generating some random normal distributions in R: with only 100 data points, there's often more than one peak. The multiple peaks may be erroneously perceived as "bimodal". A typical "large class" does not have a large enough sample size to consistently provide a smooth bell curve. Indeed, many of the distributions produced by R's `rnorm` looked very much like the grade distributions we'd seen in our own classes and called "bimodal."[1]

Interested in whether instructor perceptions affect the interpretation of noisy distributions, we designed an experiment wherein participants are presented with histograms of distributions produced by R's `rnorm` function, and asked to categorize the distribution (normal, bimodal, uniform, etc). We initially had two research questions:

1. Do CS instructors who believe in the Geek Gene categorize more noisy distributions as bimodal?
2. If we prime participants that CS distributions are commonly thought to be bimodal, are they then more likely to see bimodal distributions in the noise?

Once we'd analysed our data for those two research questions, a third research question arose:

3. If instructors label noisy distributions as bimodal, are they more likely to agree with the Geek Gene hypothesis? (i.e., is there a possible feedback loop between looking at distributions and instructors' beliefs?)

4.1 Experimental design

A difficulty in studies looking at priming effects is that you cannot state the purpose of the study in the consent form. If you do, then you are priming participants, even the participants you want in your control group. To disguise our study, we presented it as one asking people how often they saw various distribution shapes in their own classes.

We presented each participant with the six histograms shown in Figure 1, all of which we'd generated using R's `rnorm` function. We generated a few dozen histograms and selected the six histograms from that pool: one to be clearly normal (distribution 1), one that was mildly skewed (distribution 5) as though students who were failing were pushed up to 50%, one where the ceiling effect was visible (distribution 6), and three noisy distributions which had multiple peaks (distributions 2-4).

We asked each participant whether they saw this shape of distribution in their own classes (very often to never on a Likert scale), and then how they would categorize the distribution (normal, bimodal, multimodal, uniform, other).

We randomly assigned participants to one of two treatments:

Treatment 0: participants were asked whether they agreed with the Geek Gene Hypothesis, then asked to categorize the distributions, and were not being primed to think about bimodality.

Treatment 1: participants were primed to think about the common-held belief about CS grades distributions, before they saw the distributions; after that we asked them whether they agreed with the the Geek Gene Hypothesis.

The survey had five pages, which are described in Table 1. For each question we created a shorthand, in bold, for use in our analysis.

[1]One may wonder how many of the distributions generated by `rnorm` will test as bimodal per Hargigan's Dip Test. We generated 100,000 distributions with n=100, μ=60, σ=5 and only 133 distributions (1.3%) tested as multimodal per the Dip Test.

	Treatment 0				Treatment 1			
Parameter	2	3	4	5	2	3	4	5
innately-pred		-2.2 (1.2)	-22 (4.5e-2)*		0.2 (1.8)	2.8 (1.8)	5.6 (2.3)*	
all-succeed	-37 (14)*	-35 (14)*	-39 (14)*		3.5 (2.6)	4.6 (2.8)	6.9 (3.2)*	
look-histo	7.0 (57)	6.0 (57)	7.8 (57)	-22 (3.1e-6)*		-2.6 (2.4)*	-3.8 (2.1)*	-6.4 (3.1)*
look-letter	32 (2.7)	1.4 (2.1)	1.0 (2.1)	-4.1 (3.2)		27 (1.9)	29 (0.9)	32 (1.8)

Table 2: Coefficients from the `polr` regression on seeing-bimodality for each treatment; standard errors are in parentheses; * denotes statistical significance.

	LR Chisq	Df	signif?
innately-predisposed	11.0	2	yes
all-succeed	14.8	3	yes
look-histo	4.1	4	no
look-letter	6.1	4	no

Table 3: Results of the `Anova` of the regressions on the two treatments; i.e., does the relationship between a given factor and seeing-bimodality differ between the two treatments?

Because so many of the potential participants were our colleagues, we deliberately did not collect names and identifying information about the participants in the survey. We did not want to know who was or was not a participant, nor how they responded to the survey.

As a courtesy, we offered to participants the option of having their email recorded on a separate platform if they wanted us to follow up with them about the results of the study[2]. We did not look at this email list until after our analysis was complete.

4.2 Participants

We recruited 60 CS instructors, mostly from the SIGCSE members' list. Some participants were recruited from other online CS education communities, and some were recruited at ICER 2015. 53 participants completed every question on the survey; 28 were in Treatment 0 (the non-primed group), and 25 were in Treatment 1 (the primed group).

The participants who had provided their emails for follow-up purposes were debriefed. Since fewer than half of the participants had provided their email, we posted open letters to the online communities where we had recruited participants.

4.3 Results

For each participant, we computed a value we'll call "seeing-bimodality," which is the number of distributions they had categorized as bimodal/multimodal. In our data, seeing-bimodality ranged from 0 to 5.

4.3.1 *Regresion on* seeing-bimodality

We wanted to see if seeing-bimodality could be predicted by participants' responses to the questions we'd asked. The regression we performed was to model seeing-bimodality as a function of innately-predisposed, all-succeed, look-histo, and look-letter, using the shorthands from subsection 4.1.

When visualizing the results, we noticed that the relationship between seeing-bimodality and the Likert questions varied between the two treatments. To perform a non-parametric equivalent of ANCOVA, we performed an ordinal logistic regression on the two treatments separately using the `polr` function from R's `MASS` library, and then used the `Anova` function from the `car` package to compare the two.

In doing so we expected to compute 28 p values. Applying a Šidák correction to the standard alpha level of 0.05, we used 0.002 as our alpha level for this section of our analysis.

We found a statistically significant relationship between seeing-bimodality and participants' responses to the questions relating to the Geek Gene hypothesis (all-succeed and innately-predisposed), as shown in Table 2. Furthermore, when it came to all-succeed, the effect was statistically significantly stronger in the treatment which was primed to think about CS grades being bimodal, as shown in Table 3. We also observed there was a strong negative correlation between all-succeed and innately-predisposed.

We also found a statistically significant relationship between seeing-bimodality and how often participants reported looking at histograms of their grades (look-histo). This relationship was not statistically significantly different between the two treatment groups.

4.3.2 *Regression on* all-succeed

After finding a one-way relationship between grade perceptions and the Geek Gene Hypothesis, we wanted to see if there was any evidence of a feedback loop between the two. Because all-succeed and innately-predisposed correlated so highly, we found they were interchangeable as measures of belief in the Geek Gene. Since logistic regression involves only one dependent variable, we had to pick one of the two to use. We chose to do this analysis with all-succeed because the question item had been used in another study [16].

Recall that our study was set up so that a random half of the participants categorized distributions then were asked about the Geek Gene (Treatment 1), and the other half were asked about the Geek Gene and then categorized the distributions (Treatment 0). If there's a feedback loop here, we would expect that seeing-bimodality would predict all-succeed in Treatment 1, but not in Treatment 0.

Guidelines for statistical power in logistic regression are that for an alpha level of 0.05, you need 10–20 data points per independent variable in your model [18]. Because this part of the analysis requires the statistical power to reject a null hypothesis, we modelled all-succeed as only a function of seeing-bimodality, and set $\alpha = 0.05$.

For Treatment 1, we found that seeing-bimodality was a statistically significant predictor of all-succeed, as shown in Table 4. In Treatment 0, we found that it was not. This indicates that there is a feedback loop between categorizing distributions as bimodal and agreement with the Geek Gene Hypothesis.

We hence have observed evidence for the feedback loops illustrated in Figure 2.

[2]The survey was on SurveyMonkey; signing up for follow-up emails was via Google Forms.

Treatment 0			
Parameter	1	2	3
seeing-bimodality	-0.2 (0.9)	-1.1 (1.0)	-0.7 (1.1)
intercepts	-3.8 (1.2)	-2.0 (0.8)	-0.3 (0.6)

Treatment 1				
Parameter	1	2	3	5
seeing-bimodality	0.6 (1.0)	0.9 (1.2)	1.4 (1.0)	1.7 (3.2e-7)*
intercepts	-2.6 (1.1)	0.2 (0.7)	1.5 (0.8)	

Table 4: Coefficients from the `polr` regression on all-succeed for each treatment; standard errors are in parentheses; * denotes statistical significance. p values were calculated from z values using `coeftest`.

4.4 Discussion

We were initially surprised that regularly looking at histograms of grades was associated with a higher score for seeing-bimodality. This led us to add our third research question, based on the idea that it could be that the more often you look at your grades, the more it solidifies your conception of what your grades are like. This supports our observation that categorizing distributions as bimodal increases belief in the Geek Gene Hypothesis.

Our approach to priming may have led participants to believe more that grades are bimodal. Because the survey presents us, the researchers, as authority figures, and we imply that grades are thought to be bimodal, some participants could assume it to be true since we said so.

When we piloted our survey, some participants opined that they believed that some students were predisposed because of prior experience, rather than inherent brilliance.

We had hoped to recruit a larger number of participants; however, recruiting a large number of CS educators to fill out the survey turned out to be infeasible with our resources. It must be noted that we did not have a representative sample of CS educators. The educators who participate in CS education communities are generally much more invested in their teaching than their peers who do not. Furthermore, some of our participants may be familiar with Ahadi and Lister [2], which could have influenced their responses.

But we would expect the SIGCSE community to be *less* inclined to believe in the Geek Gene hypothesis than their non-SIGCSE peers. We still had enough participants who agreed with the hypothesis for us to conduct our analysis. Future work is needed to replicate our findings with a more representative sample of CS educators.

4.4.1 Supporting Literature

Our findings agree with the psychology literature: people's biases affect their decision-making more when they are judging more ambiguous information [10]. For example, Heilman et al. found that resumes of extremely qualified candidates were likely to be judged worthy of a salary increase regardless of the gender listed on the resume—but for resumes of ambiguously qualified candidates, resumes with male names were more likely to be viewed positively than those with female names [10]. As another example, Eyesnck et al. studied the interpretation of sentences as either threatening or non-threatening by people who have anxiety and by a control group [4]. They found that unambiguously threatening/non-threatening sentences were interpreted similarly between groups, but participants with anxiety were more likely to label ambiguous sentences as threatening than participants in the control group. Visual information is subject to this phenomenon also: Payne et al. showed participants a series of photos of black and white people holding either guns or ambiguous objects, and participants were more likely to identify the ambiguous object as a gun if it was held by a black person [22].

Furthermore, belief can affect judgment regardless of ambiguity. For example, Kahan et al. found that participants were more likely to get a math problem incorrect if the correct result would disagree with their political beliefs [12]. It is hence plausible that a computer scientist who believes in the Geek Gene Hypothesis could look at an unambiguously unimodal distribution and still view it as bimodal.

As for our evidence that looking at histograms reinforces belief in the Geek Gene Hypothesis, *systems justification theory* explains that once you are forced to take a position on a subject, you're more likely to believe and defend it [11].

5. THE GEEK GENE HYPOTHESIS AS A SOCIAL DEFENSE

Once again, our findings support Lister's hypothesis that CS grades are generally not bimodal and this perception stems from instructors expecting to find bimodal grades due to a belief in the Geek Gene Hypothesis. We would go a step further and argue that the perception of bimodality is a *social defense* in the CS education community.

5.1 What is a Social Defense?

In sociology and social psychology, a "social defense is a set of organizational arrangements, including structures, work routines, and narratives, that functions to protect members from having to confront disturbing emotions stemming from internal psychological conflicts produced by the nature of the work" [20].

For example, Padavic et al. [20] found that the "work-family" narrative in business is an example of a social defense: people will say that women leave the workplace because of "family", despite the large amount of evidence that women leave their jobs because of inadequate pay or opportunities for advancement [20], particularly when they see male co-workers promoted ahead of them. The "work-family" narrative is a more palatable explanation rather than to confront sexual discrimination in the workplace, and so the narrative continues.

5.2 Teacher Self-Efficacy

Guzdial reported that, per Fives [9], teachers generally have a high level of self-efficacy (great confidence in their teaching ability) at the start of their career. This then plummets as they face the realities of classroom teaching. With time, their self-efficacy slowly increases again. [9]

Teacher self-efficacy is not necessarily tied to how well they can teach: university educators often get little meaningful feedback on how their students are learning, given their large class sizes and lecture-based pedagogies. [9]

Guzdial reasoned that if an individual university-level CS educator has high self-efficacy, and sees evidence of students not learning, then it's rational for them to believe that the problem lies with the students and that the problem is innate to them—i.e., beyond the ability of the teacher to improve it [9]. Compounding this, Sahami and Piech have observed that CS educators are more aware of their top and bottom students than they are of their average students, giving educators a biased perception of their students' abilities [27].

Relatedly, Guzdial noted that CS educators have poor results, because we so frequently use ineffective teaching methods [7]. Indeed, Porter et al. recently found that performance on early assessments in CS1 correlate highly with final grades, indicating that surprisingly little learning goes on in CS1 [24]. The results of Zingaro, Petersen, and Craig would add that not only do CS educators frequently use ineffective pedagogies, they also frequently use ineffective assessment tools [33, 23].

We theorize that the Geek Gene Hypothesis is a social defense: it is easier for computer science educators to blame innate qualities of their students for a lack of learning than it is for the educators to come to terms with the ineffectiveness of their teaching.

A social defense is a phenomenon on a social scale, in contrast to Guzdial's observation about individual teachers. When numerous educators bond over how their students just "don't have it," it allows for the Geek Gene hypothesis to go from one individual's suspicion to a social narrative. And as bimodal grade distributions sometimes do occur, those cases are used to argue that this is a common and inherent phenomena in CS classes. When administrators accept this narrative and do not mandate professors to improve their teaching, the narrative can continue unchallenged.

The perception of bimodal grades provides evidence to the Geek Gene narrative that some students "have it" and some do not. And when new educators begin teaching, do not see all their students learning, and have been primed by colleagues to see bimodality, the new educator can then see this as evidence of the Geek Gene. The reproduction of the Geek Gene Hypothesis is hence social in nature.

Recent studies have found that academic disciplines in which "brilliance" is seen as necessary for success have less demographic diversity [14]. Looking at the history of science, women and people of colour were long denied entry and acknowledgment in science because they were seen as lacking the "brilliance" needed to do science [26].

If computing ability is viewed as being the result of a "Geek Gene", then educators may use this as an reason not to teach students who lack this "gene". Similarly they could lower expectations of these groups and encourage them less. Research on implicit biases consistently find that implicit biases against seeing women and people of colour as being brilliant scientists [29]. Students with disabilities or attention disorders could also be affected, or whoever else a particular educator might see as lacking the "gene". The "Geek Gene" narrative can also contribute to how women and minorities feel they do not belong in CS classes. It has been documented that underrepresented groups feel demotivated when their more experience peers boast that CS is "easy", and this could trigger stereotype threat [3].

6. CONCLUSIONS

Our analysis of UBC's grades indicates that while bimodal grade distributions can be found, they are far from typical (at most 5.8% of cases given type I error). Much more commonly, grade distributions are normal (85.1%) or skewed.

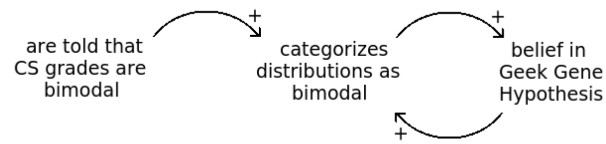


Figure 2: Individual-level feedback loops leading individuals to categorize ambiguous distributions as bimodal.

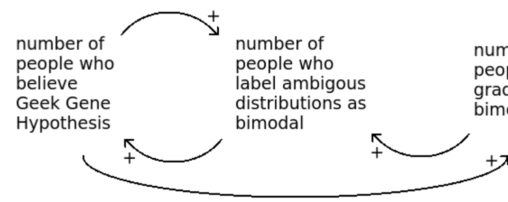


Figure 3: Social-level feedback loops leading individuals to categorize ambiguous distributions as bimodal.

Our psychology experiment found that priming participants to think about the common perception of bimodal grades leads to participants being more likely to label ambiguous distributions as bimodal. This indicates confirmation bias plays a role in the belief that bimodal grades are typical, when our (more rigourous, less anecdotal) evidence is that they are uncommon.

We also found that participants who reported beliefs consistent with the Geek Gene Hypothesis were more likely to label ambiguous distributions as bimodal. This indicates instructor beliefs play a role in perception of bimodality.

We observed that instructors who report looking at histograms of their grades were more likely to label ambiguous distributions as bimodal. As well, the random half of participants who labelled distributions as bimodal and then were asked about the Geek Gene Hypothesis were more likely to agree with it than the random half of participants who had been asked about the Geek Gene first.

Both our analysis of UBC's grades and our psychology experiment provide evidence for Lister's hypothesis that CS grades are not typically bimodal.

We theorized that the perception of bimodal grades in CS is a social defense. It is easier for the CS education community to believe that some students "have it" and others do not than it is for the community to come to terms with the shortfalls of our pedagogical approaches and assessment tools. A belief in the Geek Gene gives educators an easy way out from confronting these issues and being pushed to do better. In order for efforts to have CS taught "for all" to succeed, the CS education community needs to develop and use pedagogical approaches and assessment tools that will benefit all students.

7. ACKNOWLEDGMENTS

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Chapter 7

Discussion

I was motivated to write this thesis by the question of why gender-diversity initiatives in computing in Canada and the US have not had a macro-scale effect. I began by approaching the question using systems thinking — I thought about existing initiatives in terms of leverage and social systems; and concluded that too few initiatives were high leverage, i.e. unlikely to bring about systemic change (chapter 2).

I then shifted to using Soft Systems Methodology, leading me to consider the historical context. I identified enrolment booms as critical times when the participation of women in undergraduate computer science dropped (chapter 3). This led me to studying how CS departments were addressing the current enrolment boom, and to using micropolitics as a lens. I found that CS department policy discussions seldom considered gender diversity (chapter 4). Given that the policy discussions that were described in my survey of CS professors appeared to be more commonly determined by values rather than resources, I shifted which variety of conflict theory to use from a Marxist (resource-conflict) lens to a Neo-Weberian (value-conflict) one.

Learning more about Neo-Weberian theory led me to Witz's occupational closure theory, and to re-examining the historical context in that light (chapter 5). I identified policies and discourses as affecting the gendering of computing.

A common exclusionary discourse in computing education is that "you either have it or you don't have it". It is also commonly said that CS grades are bimodal, and construed as a separate discourse. I found that the bimodality discourse is really just a different manifestation of the "you either have it or you don't" discourse. I also observed a feedback loop that looking at CS grades distributions and categorizing them as bimodal appears to lead to CS educators more strongly believing that not everybody can succeed in the field.

7.1 A Theory of Gendered Participation in Computing

From revisiting the themes that emerged from my re-examination of the literature in chapter 5 using the lens provided by Anne Witz's occupational closure theory, I developed a theory of gendered participation in computing education. This is illustrated in Figure 7.1. Female representation is affected by the social closure of computing. The closure can be affected by policy and discursive practices.

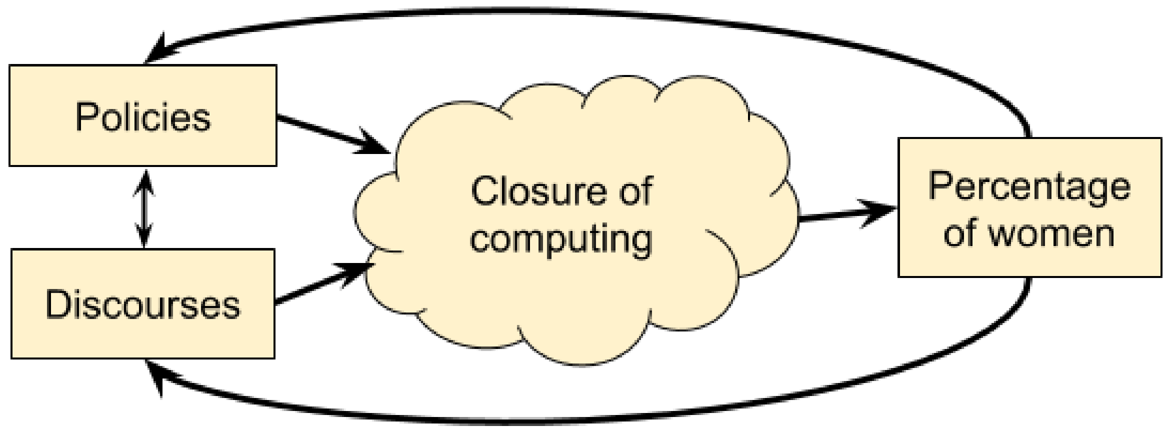

Figure 7.1: Illustration of the developed theory of female representation in computing. Policies and discourses affect the closure of computing, which in turn affects female representation. Female representation can then affect policies and discourses: for example, high female representation in the 1950s led managers to use policies and discourses to try to increase the status of the field, in turn closing it and affecting female representation in turn. Low female representation has also been used to create policies at universities like Carnegie Mellon and Harvey Mudd to reduce the closure of computing and improve female representation.

Witz describes two major strategies for exclusionary closure: exclusion (reducing access), and demarcation (boundary work). Both contribute (and have contributed) to the closure of computing. Exclusionary strategies have included not allowing married to work after WWII, and in contemporary times, preferentially admitting students to CS undergraduates who have high school CS. Demarcationary strategies include the historical division of labour in early computing (e.g., a woman "coder" working for a male "planner"), and the contemporaneous demarcation between CS and IS/IT.

7.1.1 Policy Practices

Policy practices are a consistent theme in the literature on the history and geography of women in computing. Formal gatekeeping practices such as university admissions policies, hiring policies, research grant reviewing, peer review [29], professionalization, and credentialism all affect female representation in computing. For example, the use of personality tests in hiring has historically had an effect on who is hired — and the subsequent image of what a computer scientist looks and acts like.

Formal policies can also be used to open computing. For example, opening up new pathways for "non-traditional" students to enter the field has the promise to improve diversity, and has played a role in achieving meso-level change at universities such as Carnegie Mellon and Harvey Mudd.

Social gatekeeping factors — such as professors creating a "chilly" atmosphere in their so-called "weeder courses" — are also the result of policy practices. Student-to-faculty ratios and the training and composition of faculty also are policy practices which affect the learning environment for students, in turn affecting the closure of computing. Policy practices such as providing first-year research experience for undergrads or taking students to Grace Hopper to provide a sense of community for female students also act to counteract the closure of computing.

7.1.2 Discursive Practices

As documented by Abbate [2] and Cukier [54], the discursive practice of presenting computing as a field of math and/or engineering acts to close the field. Efforts to highlight the multifaceted, interdisciplinary nature of computing act to open the field — and are attributed to the higher percentage of women in computing at some US universities.

The discursive construction of gender also matters. In Malaysia, gender roles are such that office work is "women's work" and outdoor physical labour is "men's work", and at the same time computing is presented as an office job and is female dominated [144]. Note that when computing was seen as a clerical job in the US and the UK, it was also female dominated [171, 66, 2, 109]. When the discursive presentation of computing is compatible with gender roles, we see more women in computing. Whether this is an appropriate goal for gender equality is debatable: if we discursively recast computing as compatible with traditional gender roles, we in turn reinforce these gender roles. For a further discussion of why this is counterproductive, see [193].

Another discursive shift that may be productive is moving from the "leaky pipeline" metaphor to a metaphor of "pathways." The leaky-pipeline metaphor has been critiqued and problematized for establishing a limited view of who may be in computing, and further marginalizing "non-traditional" students [115, 187, 34, 48, 145, 204].

Another factor identified in the literature is that the discourse of growth (or fixed) mindset has an effect both on the social experience of computing students as well as whether students feel they should study CS. As Leslie et al [128] as well as Cohoon [46] has documented, we see more women in academic fields where faculty believe that any student can succeed.

Discourse can also be used to determine the boundaries of computing. Programmes such as digital media, cognitive science, computational biology, and information systems often have higher percentages of women [72, 95]. Discursively positioning these majors as part of computing would result in groups with more women being considered part of computing, in turn counteracting the closure of computing.

7.1.3 Interactions: Discourses and Policies

There are interactions between policies and discourses: policymakers are affected by discursive strategies and the effects of policies can promote or hinder particular discourses. The Generation CS report observed that CS departments which considered diversity in their policy-making had a higher percentage of women in their CS programmes [49]. More work is needed in CS education research to examine the process of policy-making in CS programmes.

7.2 Re-examining Earlier Work

In this thesis, I presented three papers which were written before I began to consider closure theory in my work. How do these papers stand up with this new lens?

Chapter 2. In *Scaling up Women in Computing Initiatives: What Can We Learn from a Public Policy Perspective?* I considered initiatives in terms of leverage, but didn't fully investigate the dynamics of the CS educational system. That said, many of the things I wrote are congruent with what I have since determined about the system; for example, I noted that it would be a high leverage change for us to change the narrative that not everybody can succeed in computing. Notably, not all the policy changes I examined were high-leverage, giving us a reminder that just because it is policy does not mean it is necessarily system-changing.

In the paper, I also argued that Universal initiatives — ones that target the whole population rather than a sub-population known to be marginalized — are more likely to have large-scale effects. I would now argue that this is also because Universal initiatives are more likely to affect the closure of the field, since they work to change the field as a whole.

Chapter 3. *A Historical Examination of the Social Factors Affecting Female Participation in Computing* (ITiCSE 2014) noted the social construction of "women's work" as important in the historical gendering of computing. This is an observation that also holds in looking beyond the West: in parts of the world where computing is constructed as "women's work", such as Malaysia, we see more women in the field [144]. We also see in this history that computing has been subdivided when women are present: men got to be the "planners", whereas the low-status "coding" was for women. In my rewrite of the paper in chapter 5 I make a point of using the language of closure in describing this history.

In the ITiCSE article, I described the conflict between generations of women. In light of my model, I would now also describe it as dual closure: first generation women would exclude the second generation women they saw as "weak" and "too feminine".

Chapter 4. *How CS Departments are Managing the Enrolment Boom: Troubling Implications for Diversity* (RESPECT 2016) focuses on policy, without considering discourses. That said, some discourses are implicit in the paper. Participants noted "quality of students" as a medium factor in their admissions policy-making, and open-ended feedback indicated that this reflects a discourse that we should only seek to admit the "best and brightest" students. The focus on "best and brightest" can be gendered, since there are gender biases in how "best"/"bright" is perceived [195]. This focus also can amplify social inequalities, by selecting for students who have the most cultural capital to begin with [26]. This admissions strategy is also not the only one: alternate visions would include admitting students who would most benefit from the programme, admitting students via lottery, admitting students who would enrich student culture in the programme, etc.

Future work is needed to examine the relationship between brilliance discourses and how policy-makers are affected by it.

7.3 Future Work

7.3.1 Admissions Policies

In chapter 4, I identified that, for the most part, policymakers are not considering diversity when making policies in response to the enrolment boom — and some of their discourses (e.g. brilliant students, weeder courses) may be actively undermining diversity. Future work would observe the policymaking in action.

A case study site that would be interesting to me is the University of Alberta. As a result of funding cuts across the province, the Department of Computing Science ended their "post-baccalaureate" programme in CS, which allowed students with a degree in another field to complete a degree in CS in two years. A similar programme at the University of British Columbia has consistently attracted more women than traditional CS programme — in some years more women than men [72]. Yet the University of Alberta never kept statistics on the gender balance of the post-baccalaureate programme, and gender was apparently not considered when ending the programme.

I would also like to investigate across multiple universities whether espousing the bimodality discourse and/or the "Geek Gene" discourse correlates with policy preferences with regard to admissions to CS programmes. Furthermore, does espousing the bimodality and/or "Geek Gene" discourses correlate with established measures of gender bias? Further understanding the relationship between discourse and policies will strengthen our understanding of how closure operates in computing.

7.3.2 Other Excluded Groups

This thesis focused on gender diversity in computing. However, women are not the only group currently excluded from the field. More work is needed to understand why Black, Hispanic/Latinx, and Indigenous students are under-represented in computing education, along with students with disabilities, students from low-SES backgrounds, and LGBTQ+ students.

While there are likely commonalities across all of these groups' exclusion from computing that stem from the closure of the field, future work would need to properly investigate this. In particular, the historical contexts of each of these group's exclusion from computing is under-studied, and would require working with primary sources rather than reinterpreting secondary sources.

7.3.3 Discourses of Women in Computing

The social construction of who gets to be a "woman in computing" is also worthy of further study. What do we even mean by "woman" and how can we include trans/non-binary individuals in computing? How can we improve computing for its gender minorities without reinforcing a notion of a gender binary? And returning to who gets to be a "woman in computing", how do women with multiple excluded identities fit into this discourse? Futhermore, how do immigrant women and women of colour respond to nationalist discourses [207] that CS should be taught to all Americans because "immigrants are taking our jobs"?

A space which plays a large role in the construction of the "woman in computing" discourse is the Grace Hopper Celebration. Abbate describes the founding of the conference in 1994 as a radical act of solidarity-building for women, that "a technical conference for women had the potential to expose the prevailing culture of computer science as being masculine rather than gender neutral" [2]. By Abbate's description the conference works against "popular descriptions [of computing] to paint an alternative image of computer science as female-friendly and of women as comfortable with technology" [2].

But Sturman's institutional ethnography of the conference in 2005 depicts this "alternative image" as itself problematic. Per Sturman, the conference constructs what a gender-inclusive computer science looks like in a way which reinscribes gender norms, is heteronormative, and excludes women of colour and immigrant women [193]. Furthermore, Sturman describes the conference as a glamorized job fair where women are commodified and companies vie to hire token female workers. Contemporary criticisms of the conference indicate this is still the case [177, 140, 127, 149]. In future work I would like to study the history of the conference, and interview women involved with the conference over the years. How did a radical act of feminist solidarity-building over time develop into a site of dual closure and neoliberalism?

Another study I would like to conduct is to interview creators of other gender diversity efforts in computing. What was their design process? Their motivation? In my work I have criticized many diversity efforts as being low-leverage — but why is it that so many well-intended efforts are low-leverage?

7.4 Conclusions

Occupational closure provides a theoretical explanation for the historico-geographical variations in the percentage of women in computing. This is supported by the existing literature on the historical and geographical variations in female representation in computing.

The closure of CS is affected by policy and discursive practices. For example, having multiple pathways into a CS major is a policy practice which encourages female representation [136], and historically female representation suffered when pathways were reduced [168]. Discursive practices such as the notion that you need an innate ability to succeed communicate that not everybody can succeed in the field, which has also been linked to reduced female participation [128].

Female participation in computing has been historically used as an impetus to change policies and discourses in computing. Low participation was used to motivate policy changes at universities such as HMC and CMU in the early 2000s [136, 6]. On the flip side, the high participation of women in computing in the mid 20th century was used to motivate the closure of computing [2, 109].

Understanding female representation in computing in terms of social closure gives us not only an explanation for the historico-geographical variations, but also provides a lens to understand and improve female representation in the present-day anglosphere. Closure theory gives us insight as to why gender diversity efforts in computing have not had a macro-level effect. Where we have seen success at the meso-level, such as at CMU and HMC, explicit steps were taken to open up computer science. At CMU, admissions policies were changed, different entry points to CS1 were created, and steps were taken to improve teaching quality. Multiple entry points were also created at HMC, students across the whole college were mandated to take an introductory CS class, and research opportunities were created for undergraduates (including attending the Grace Hopper Conference). Diversity initiatives which do not target the underlying causes of the masculinization of computing are unlikely to shift the needle.

To achieve macro-level change, we need high- and medium-leverage changes in our educational system (chapter 2). We need to consider the historical context of our system (chapter 3). We need to consider gender and closure in making policy in response to enrolment booms (chapter 4). We need to consider that the experiences and goals of women in CS are not homogeneous, and that the women who have achieved leadership positions are coming from a different place from the women now entering the field (chapter 5). We need to counter discourses that not everybody can succeed in CS (chapter 6).

And for those of us working in the area of gender and computing education research, we need praxis. CS education researchers too seldomly use sociological and/or critical theorists in their work, despite gender being a social phenomenon. And critical sociologists too seldomly share their work in ways which can be found or understood by CS education researchers. One of the contributions of this thesis has been a bridge between the two communities: I bring new theoretical and conceptual lenses to the CS education literature, and incorporate the work of critical feminists who have studied the gendering of CS and had not been taken up by the CS education community.

Changing the gender dynamics of computing is no easy task, and cannot be solved by one thesis or even one individual. This thesis makes contributions to understanding a real-world problem, but is only one piece of the puzzle. It falls upon all of us to come together and make the change that computer science needs — not just for the sake of the computing community, but for everybody affected by computing in their lives.

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