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Supporting women's persistence in computing and technology

A case for compulsory critical coding?

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Abstract

Purpose – This paper aims to investigate what factors influence women's meaningful and equitable persistence in computing and technology fields. It draws on theories of learning and equity from the learning sciences to inform the understanding of women's underrepresentation in computing as it investigates young women who showed an interest in computing in high school and followed-up with them in their college and careers.

Design/methodology/approach – The mixed-methods approach compares data from quantitative surveys and qualitative focus groups and interviews. The sample comes from database of 1,500 young women who expressed interest in computing by applying for an award for high schoolers. These women were surveyed in 2013 and then again in 2016, with 511 women identifying themselves as high schoolers in 2013 and then having graduated and pursued college or careers in the second survey. The authors also conducted qualitative interviews and focus groups with 90 women from the same sample.

Findings – The findings show that multiple factors influence women's persistence in computing, but the best predictor of women's persistence is access to early computing and programming opportunities. However, access and opportunities must be evaluated within broader social and contextual factors.

Research limitations/implications – The main limitation is that the authors measure women's persistence in computing according to their chosen major or profession. This study does not measure the impact of computational thinking in women's everyday lives.

Practical implications – Educators and policymakers should consider efforts to make Computer Science-for-All a reality.

Originality/value – Few longitudinal studies of a large sample of women exist that follow women interested in computing from high school into college and careers particularly from a critical educational equity perspective.

Keywords Equity, STEM, Computing, Mixed-methods, Women, CS-for-All

Paper type Research paper

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Introduction

In 2016, then President Obama announced his vision for the "Computer Science (CS) for All Initiative" in which all students would have "hands-on computer science and math classes that make them job-ready on day one" (State of the Union Address). The CS-for-All initiative was part of a broader campaign to support and expand science, technology, engineering, and mathematics (STEM) education and employment opportunities for American youth. We are purposefully calling attention to this connection between CS and broader STEM activities as our research has been investigating what role early computing interest and opportunities for young women play in supporting their persistence in both computing and other technology fields. In this article, we compare the results of a quantitative survey measuring predictive factors for young women's persistence in CS and non-CS college majors, with the findings from qualitative interviews and focus groups of the same population of young women. Specifically, we present research findings from surveys, interviews and focus groups that followed-up with young women in college and early careers who had shown an interest in computing during high school as demonstrated by applying for the National Center for Women and Information Technology (NCWIT) Aspirations in Computing (AiC) award.

The results of our qualitative and quantitative data differ. The qualitative data demonstrate that multiple factors influence women's persistence in CS including not only women's experiences but also how participation and persistence in computing is defined (Weidler-Lewis *et al.*, 2017). Analysis of our interviews and focus groups suggests that we ought to have an expansive view of both CS participation and how to cultivate this participation, which would encompass more than engaging in coding as the only outcome measure of persistence. Our survey data, on the other hand, show that women who persist not only in CS (e.g., those fields that require computational thinking) but also other non-CS technology fields (i.e., computer graphic design) had access to programming opportunities as youth (Weston *et al.*, 2019). Thus, we draw a narrower conclusion that prior experience with coding specifically – as opposed to other related technology experiences such as game design or web development – is the strongest predictor of women's persistence in both computing and technology related majors. In this article, we analyze these seemingly disparate findings within a coherent narrative and what this means for supporting women's persistence in computing and technology. We seek to understand what factors influence women's meaningful participation and persistence in computing? And, how do our qualitative and quantitative findings on women's persistence in computing complement and/or contradict each other?

Background

The underrepresentation of women in computing continues to be an unsolved yet highly investigated problem. According to the National Center for Educational Statistics, the percentage of women pursuing CS-related majors has declined over the past three decades from 37 per cent of bachelor's degrees earned in 1985 to 18.7 per cent in 2016 [National Center for Women and Information Technology (NCWIT), 2018]. Although women enroll at lower rates than men, there is little difference in attrition rates by gender in college degree programs (Cohen and Deterding, 2009; Dee and Gershenson, 2017). Research has focused on what spurs interest in computing such as early exposure, access to rigorous computing opportunities and peer support (Google, 2014; Teague, 2002) and what hinders women's participation in computing, including gender-bias, micro-aggressions and lack of community support (Camacho and Lord, 2011; Rosson *et al.*, 2011; Smyth and Nosek, 2015). The problem of underrepresentation has persisted for so long that numerous efforts have been made to synthesize all the research to date and possible solutions (Corbett and Hill, 2015; Kanny *et al.*, 2014;). Despite the enduring problem of the lack of women's participation in computing, there have been multiple calls to increase their participation [National Research Council (NRC), 2011; National Center for Women and Information Technology (NCWIT), 2015; The White House, 2009]. Our research attempts to support this call.

NCWIT is a non-profit community organized to support the increased meaningful participation of women in computing. Multiple strategies are used to further their mission, including convening leaders to collaborate on how best to implement change; offering award programs and incentives for girls, young women and educators in computing; and providing research-informed resources for stakeholders wishing to change their computing environments for students and professionals alike. The research presented here comes from a mixed-methods study of one of their prominent award programs for high school young women: the Aspirations in Computing (AiC) award. The research was conducted over six years and includes AiC application survey data, data from survey instruments administered in 2013, 2016 and 2018, and data from interviews and focus groups of 90 women conducted between 2012 and 2017. The research team is interdisciplinary and brings multiple perspectives on education, learning, and the social factors that interact with women's persistence in computing. Given our differences, and the longevity of the project, our thinking and our approach to analysis have evolved over time and this evolution is apparent in the presentation of this work below. Next, we present our current thinking on equity and women's meaningful participation in computing before presenting the model used for analyzing persistence.

Equity and computer science education

As Social and Learning Scientists, we are mindful of the ways in which our research can disrupt or contribute to injustice and inequity in our society. For example, the way in which the underrepresentation of women in computing is often framed – and we invoked this framing by including Obama's call for a STEM ready workforce – is that equity would be achieved if women were represented in 50 per cent of computing jobs. Although this is a goal that as researchers for NCWIT we hope is attained, we also recognize that it oversimplifies both what "equitable" participation entails and the ways in which computing as a discipline is tied to systems of power and embedded within complex sociopolitical contexts that are inherently fraught with competing economic and political interests (Vakil, 2018). Furthermore, we have shown that "successful" participation in STEM activities does not necessarily mean that young women do not still suffer gendered consequences despite their success (Weidler-Lewis *et al.*, 2016), and pushing women through the "STEM pipeline" only to earn significantly less money than their white male counterparts is hardly equitable (Sengupta-Irving, 2015). Therefore, we must question how we define our goals for success and equity in STEM disciplines (Carlone *et al.*, 2011).

Another way of framing equity in computing is to recognize that computational thinking and computer literacy are fundamental problem-solving skills that all students ought to have a right to develop (diSessa, 2001; Wing, 2006, 2008). This perspective varies in kind. For example, Soloway (1993) argues that programming and computational modeling represent core scientific practices that ought to be part of the curriculum, while other educators see computational literacy as any other form of literacy that should be recognized and valued as a way in which we make sense of our place in the world (Ito *et al.*, 2013; New London Group, 1996). As Gutiérrez (2008) would argue, literacy tools empower youth and support their individual and collective pathways toward just and equitable futures. In this socio-critical tradition, Lee and Soep (2016) call for critical computational literacy that brings together the power of computational thinking (Wing, 2006) with critical consciousness (Freire, 1993). From this perspective, youth have the opportunity for both self-determination supporting their pathways toward their chosen college and careers and recognizing themselves as cultural-historical actors with the ability to create a more just and equitable world. We as educators, then, simultaneously can have the goal of increasing participation from a purely numbers perspective such that women represent 50 per cent of computing majors and careers while also working to change the social practices of computing so that they are just and equitable for all.

As educators committed to equity, we attempt to understand learning holistically and not just analyze how people learn but also interrogate "for what," "for whom," and "with whom" learning takes place (Philip *et al.*, 2017). With this in mind, we recognize that advocating for computer science education for all means we need to be vigilant in promoting equitable computer science education. We take learning to be a process of becoming in which identities are constructed through participation, and through participation communities are produced defining who belongs and is valued (Holland *et al.*, 1998; Packer, 2010). An individual's identity is shaped both by her goal-directed activity and the subsequent recognition by her community (Gee, 2008). Learning is a mutual process constituting both the individual and her community. Although it is important to focus on the process in its entirety, the research described below focuses mostly on the individual as our survey and interview protocol were based on Lent's (2000) Social Cognitive Career Theory (SCCT).

SCCT holds that a variety of person, environmental and behavioral variables influence career choice. The model defines internal and external factors that support or inhibit career and education decisions, including interest, self-efficacy, outcome expectations, perceived social supports and intention to persist. One of the premises of the model is that students with high self-efficacy, or confidence in their computing understanding and skills, will be more likely to persist in computing in college and careers. Increased self-efficacy promotes favorable outcome expectations or the belief that actions will result in expected outcomes. Self-efficacy and outcome expectations alone and together support career interest and goals. Career choice is also influenced by contextual factors such as social support. The SCCT model has been used to study factors related to the under-representation in STEM (Fouad and Santana, 2017; Lent *et al.*, 2008, 2011) and so we selected it as our initial survey model.

Methods and data

The research question is as follows:

RQ1. What factors influence women's meaningful participation and persistence in computing?

To answer *RQ1*, we engaged in two distinct data collection phases:

(1) a series of surveys, including the initial application survey; and

(2) qualitative interviews and focus groups.

Using a "convergent parallel design" (Cresswell and Plano Clark, 2011), the results of each investigation are compared and triangulated to give a more complete understanding of women's persistence in computing. In this section, we describe the sample for the two strands of research followed by a description of each strand. After presenting the findings for each, we integrate the results and draw connections to answer the question, 'How do our qualitative and quantitative findings on women's persistence in computing complement and/or contradict each other?'

Sample

The sample of women in this research comes from a database of winners and non-winners for the NCWIT AiC Award. Anyone who registered on the program website between 2009 and 2013 or had won the award in 2007 or 2008 (prior to the existence of a digital platform) were eligible to be included in the sample. The award program began in 2007 and has attracted thousands of young women with some affinity toward computing or technology. The database, however, also includes any young women who registered on the award's website but did not submit an application for the award. As part of the registration and application process, young women complete an "application survey" in which they rate a list of 20 computer skills and activities according to how often they engage with each ranging from "Not at all," "Only a little," "Pretty much" and "A lot". We have application survey data from nearly all survey respondents.

Quantitative survey

As part of this longitudinal study, a series of three surveys were fielded between 2013 and 2018 (Table I). While the survey was revised with each administration, the same set of constructs was included in each administration to allow for case-level comparisons across time.

The initial survey administered in 2013 to the women in the database was based on the SCCT model as described above and sent via SurveyMonkey. NCWIT researchers developed the survey, and the five constructs of the SCCT model were represented by 34 items: 9 interest items, 7 confidence items, 5 intent to persist items, 7 perceived social supports/barriers items and 6 outcome expectation items. Survey items were organized in blocks aligning with the SCCT model. Regarding interest and confidence, items asked about designing computer games, trying new computer software, fixing or building computers, programming computers, inventing technology and finding technological solutions to world problems to name a few. Items designed to measure perceived social support asked questions about perceived family and peer support such as, "My family likes me to learn about technology" and "I believe people like me can do well learning computing". A final open-ended question asked women about their college, military or work position they were holding at the time of the survey.

The second administration in 2016 of the survey went to the 1,500 respondents from the first survey administration. In the 2016 survey, 511 respondents were either in college or early career. The second survey contained the same questions as the first but included questions asking the women about their college major or occupation and title, if they were in the workforce. From this "where are you now" question, a dependent variable of "persister/non-persister" was identified. The levels of this variable included: *CS-persister* for those women who were pursuing or who had graduated with a CS or Computer Engineering degree; *Tech-persister* for those women who were pursuing or who had graduated with a technology-related degree (other than CS or Computer Engineering); all others respondents made up the *Non-persister* group. Table II shows the number of women in each group.

Table I. Survey implementations and response rates

Year	No. in sample	Respondents	Response rate (%)
2013	9,860 (all those who had registered on the website)	1,613 (1,500 usable)	16
2016	1,500 (all usable surveys from Survey #1)	885	59
2018	1,500 (all usable surveys from Survey #1)	795	53

Our survey data were analyzed to see which model of persistence was a better predictor of continued CS persistence in college or beyond. The first model was based on SCCT, and the second model is called the "domain" model. The domain model included the same items as the SCCT model, but they were rearranged to allow for a different analysis. In the SCCT model, one item from each subdomain (e.g. gaming, programming and inventing applications) was represented in each psycho-social SCCT category (e.g. interest and confidence). In the domain model, we grouped items by subdomains corresponding to a particular underlying skill including programming, game design and inventing new applications. See Table III for examples. We did this to learn which grouping method better fit the data while controlling for number of total parameters estimated by the model. Although the original SCCT model (Lent *et al.*, 2000) includes "intent to persist," we did not include this item block in our analysis because it was redundant with our persister variable mentioned above, which measured actual versus intended persistence.

We used the statistics software SPSS AMOS 24 to conduct confirmatory factor analysis (CFA). CFA tests the comparative fit of hypothesized model (e.g. SCCT) with alternative models (e.g. the domain model) to empirical survey data. We used the following fit indices: Chi-square, root mean square of approximation (RMSEA), comparative fit index (CFI) and sequence robust multi-array analysis (SRMA). Using the Maximum Likelihood estimation procedures, we followed the best practices for standards of model fit (Hu and Bentler, 1999; Mueller and Hancock, 2008). After checking the adequacy and assumptions of the data for modeling we found:

- an acceptably high ratio of persons to parameter for both the domain and SCCT models, 14:1;
- univariate and multivariate normality were within acceptable ranges for skewness and kurtosis for individual variables and multivariate normality; and
- the reliability of composites were adequate to good, ranging from 0.77 (gaming) to 0.85 (programming).

Group name	CS-persister	Technology-persister	Non-persister
No. of women	$n = 177$	$n = 137$	$n = 181$
Description	CS and Computer Engineering majors	Pursuing (non-CS) information technology related major or other engineering major	Students not in CS, engineering or information technology related majors

Table II. Three groups in the persister outcome variable

SCCT interest construct (used for fielded survey)	Domain model for programming construct (used for analysis)
Regardless of whether or not you have actually tried it [. . .] How *interested* are you in *programming computers* or other technologies (In other words, writing code)? How *interested* are you in *thinking of new technology inventions* (For example, new apps or software, improved tablets or MP3 players)? How *interested* are you in actually *creating new technology inventions* (For example, new apps or software, improved tablets or MP3 players)? How *interested* are you in *finding technological solutions to world problems?*	How interested are you in programming computers or other technologies (In other words, writing code)? How confident are you in your ability to program computers or other technologies (In other words, writing code)? How much do you want to learn more about programming computers or other technologies?

Table III. Example constructs from the SCCT and domain models

Based on the data from the 20 items from the applications survey, we created four factor variables using Maximum Likelihood Extraction and Orthogonal rotation procedures; the four factors accounted for 43 per cent of total variance. These four factors were programming, technology work and community, multimedia and network. Composites for these factor variables were created with the "regression" method in SPSS. For our predictive models, we used multinomial regression to (simultaneously) predict the CS-persister and the technology-persister dependent variables. Comparisons for multinomial regression were between technology-persister and non-persister on one hand, and CS-persister and non-persister on the other. A more thorough description of our analysis is presented in Weston *et al.* (2019).

Interviews and focus groups

The interviews and focus groups of 90 women took place in two phases. The initial 64 women interviewed were recruited from the AiC award sample described above and interviewed either individually via telephone, videoconference or in person or via videoconference focus group between 2012 and 2015. We recruited women through both email and personal phone calls, and they were offered an incentive of an iTunes gift card to participate. Both the individual interviews and focus groups followed a similar semi-structured protocol that inquired about the women's experiences and perceptions about computing and SCCT concepts and others such as belonging and identity relative to computing. We were also interested if winning or not winning the AiC award impacted their attitudes about computing. Our initial analysis showed that winners of the award were more likely to be persisters (39 out of 41, 95 per cent) than non-winners (11 out of 20, 55 per cent).

In our initial sample, award winners (in particular national winners as opposed to regional winners) and women who persisted had greater representation than non-award winners and non-persisters. In the second phase of the qualitative study, we increased our efforts to focus on these latter categories. We focused our recruitment on those women who:

- had returned the study surveys administered in 2013 and 2016;
- were not national winners or runners up for the award;
- were no longer pursuing computer science based on their responses to survey questions asking what they were currently studying or what field they were working in; and
- had not been interviewed for this project before.

In total, 281 women fit these criteria. We utilized stratified random sampling to select potential participants to contact, stratifying the sample by winner and application status (i.e. seeking non-winner and no application). We further stratified the sample by race and ethnicity to ensure representation from multiple racial and ethnic groups. We recruited from this stratified sample and contacted 59 women. We also noted that our original recruitment script and interview protocol may have turned away women who did not persist in computing, as they may have appeared to implicitly judge women who were no longer persisting in computing, so we reframed the study to emphasize the factors and experiences that influenced women's educational and career choices more broadly instead of computing alone. The interview guide for non-persisters included questions about what women were currently doing and the factors influencing their choices, their high school experiences, the roles of gender and race/ethnicity in their educational and career decision-making and their sense of belonging in their chosen field. However, we retained the core questions about computer science and engineering experiences to facilitate comparisons between persisters and non-persisters. Recruitment involved direct solicitation, including personalized emails and phone calls and the incentive was increased to a $75 Amazon gift-card. In Phase 2, we stopped recruiting after we had interviewed an additional 26 women.

All interviews and focus groups were recorded and transcribed. Transcripts were uploaded into Dedoose, a qualitative analysis program. We used a combination of a semi-emergent approach to content analysis (Cresswell, 1998) and grounded theory (Glaser and Strauss, 1967) to develop our coding scheme. Some codes were created based on SCCT (e.g. self-efficacy, outcome expectations) and those identified in reviews of the literature such as Kanny *et al.* (2014) review of the past 40 years of research on women in computing which identified five metanarratives: individual background characteristics; family influences and expectations; structural barriers and affordances in K-12 education; psychological factors, values and preferences; and perceptions of STEM fields. To this, we also added a sixth sub-code, post-secondary barriers and affordances, because the majority of women who participated in the interview component of our study were in college or working. We also remained open to constructs that emerged from the data themselves such as belonging, and we iteratively refined our codes.

Each transcript was coded by at least two researchers and all new sub-codes were reviewed by a second researcher to make sure they were consistently applied. During coding and analysis, the research team met regularly to define and refine codes and work toward inter-rater agreement. Coding disagreements were discussed by the research team. Often the disagreements were due to the different experiences and bodies of literature that individual researchers were familiar with. These discussions enriched our understandings of the data from multiple perspectives.

Findings

In this section, we present condensed findings from our two strands of research. A summary of our findings allows us to make comparisons between the qualitative and quantitative data that might otherwise be obscured by a comprehensive discussion of each study alone. For a more detailed description of the survey findings, see Weston *et al.* (2019) and a more detailed description of the qualitative research see DuBow *et al.* (2017). By presenting the findings from the two strands separately, we address the question, "How do our qualitative and quantitative findings on women's persistence in computing complement and/or contradict each other?" Taken together, our two strands of research weave an argument for how best to understand the data used to answer the question, "What factors influence women's meaningful participation and persistence in computing?"

Survey findings

As discussed above in our analysis we examined what prediction model was a better fit for our survey responses including the shortened SCCT model with the outcome variables removed and the domain model, each using the same 16 survey questions in different configurations. We tested these models and the original (longer) SCCT model and calculated fit-indices, factor loadings, and factor correlations. Items most associated with Programming showed strong factor loadings from 0.62 to 0.90. Those associated with Game Design ranged from 0.55 to 0.89. Three items constituting Inventing New Applications had factor loadings from 0.58 to 0.84. Finally, the four items making up Social Support had factor loadings from 0.47 to 0.86. Confirmatory Factor Analysis showed that the original SCCT model fit the data poorly according to cutoffs defined by Hu and Bentler (1999) with c2 = 2,472, df = 293, CMIN/df = 5.3, CFI = 0.77, RMSEA = 0.13 and SRMR = 0.077. The shortened SCCT fit slightly better, but still fit poorly with c2 = 652, df = 84, CMIN/df = 10.5, CFI = 0.81 and SRMR = 0.087. The domain model on the other hand met or nearly met model fit standards with c2 = 242, df = 84, CMIN/df = 2.9, CFI = 0.95, RMSEA = 0.061 and SRMR = 0.067.

Because the domain model was a better fit to our empirical data, we examined how well composites made from the domain model predicted computing persistence from high school to college. Given that our sample contains longitudinal data of women's actual persistence, we are uniquely positioned to measure factors related to actual persistence instead of merely intent to persist. Furthermore, our large sample of women had a variety of computing experiences based on their responses to the initial application survey. We had the opportunity to examine if the composite variable from the best fitting model predicted the dependent variable for both CS-persisters and technology-persisters. To do so, we created a multinomial regression model that compared them.

The Programming composite variable significantly predicted CS persistence ($p < 0.001$), with one standard deviation unit increase corresponding to approximately four times more likely persistence (odds ratio equal = 4.12). Programming also significantly predicted persistence for technology-persisters ($p < 0.001$), with a lower odds ratio of 1.6. Other variables were significant predictors of persistence such as being AiC award winners and taking the CS Advanced Placement Exam. We were surprised to find that variables such as social support and game design did not predict persistence in any model. Although there are limitations to the survey that could explain the lack of predictive power for social supports that could be addressed in subsequent measures, we argue that it is significant that Programming engagement was the best predictor of persistence in both CS and the larger category of Technology persistence. Our findings suggest that high school girls who become involved with the more technical aspects of computing early on have a greater likelihood of pursuing CS or other tech-related majors in college.

Qualitative findings

Unlike our survey findings in which one factor, early programming experience, was clearly significant for women's persistence, our qualitative data showed that multiple, even redundant factors influence individual women's persistence rather than one factor alone. It is easy to identify where some women land on the spectrum of supporting and inhibiting factors. For example, when comparing the profiles of Joan, a persister, and Sophia, a non-persister (pseudonyms), two women interviewed during the first qualitative phase, you can see that one has multiple supports while the other does not. Joan's persistence is attributable to having parents in the tech industry, living in the Pacific Northwest – one of the densest technology areas in the USA – having access to AP computer science classes and having friends accompanying her to tech-related afterschool activities. Sophia, on the other hand, grew up in an agricultural town in California's Central Valley, where "they didn't really do much about technology". She was a first-generation college student, her community was lacking in "computer people" as she called them, and her high school only offered one computing class. Despite the fact that she "really liked" her computing class, she also liked animal science. This field would allow her to stay close to her family and she believed it would be easier for her to find a job after graduation.

This is not to say that all young women like Sophia will not persist. Of the first 64 women we interviewed, over three quarters of them persisted in computing. We focused on identifying themes related to women's persistence including those women who unlike Sofia persisted in face of obstacles. We identified three general themes that contribute to women's persistence:

(1) sufficient exposure to learn computing skills, whether in school or out of school;
(2) sufficient community support, including teachers, parents, and peers; and
(3) respect and encouragement to feel they belong in computing and, thus, to develop a computing identity.

The third theme called into question our various views as researchers of what identity means. At a basic level, an identity refers to a particular kind of person in a given context (Gee, 2000), but the construction of identities occurs through participation (Lave and Packer, 2008). As we more closely examined women who were or were not persisting, we began to question both how we as researchers and the women themselves viewed "participation in computing," recognizing the need to be explicit regarding how we defined participation in computing (Weidler-Lewis *et al.*, 2017). Participation in computing often has been defined by a disciplinary perspective that values computational thinking as being the critical skill representing CS. We argued that this perspective unduly excludes some women (and likely men) from being seen as participating in a more expanded view of computing, namely a community of practice view of computing (Lave and Wenger, 1991). From this perspective, an individual is seen as a member of a community not necessarily because of an acquired skill, but rather because she is seen and sees herself as identifying with the community.

To demonstrate this, we use the example of two young women who would be classified as "not persisting in computing" according to the disciplinary perspective because they were not explicitly engaging in computational thinking; however, they were both sophisticated users of technology who many would argue should be seen as "persisting in computing," including themselves. We also complicate our understanding of women's persistence by questioning the roles teachers play in helping to alleviate the underrepresentation of women and in our efforts to support women in computing: Should we encourage women who want to teach the women to go into computing? If so, how do we classify their participation and persistence? After all, former President Obama believed we needed to make it "a priority to train an army of (STEM) teachers [. . .] to make sure that all of us as a country are lifting up these subjects for the respect that they deserve" (April, 2013).

In the second phase of the qualitative interviews we focused our efforts on more deeply understanding non-persisters. Of the 26 women we interviewed during this phase, 23 were no longer pursuing computing based on a narrower definition of computing that only included computer science or computing engineering disciplines. If we consider a broader definition of participation in computing, such as web design and graphics, and if we include STEM teaching, seven more women from both phases of interviewing could be counted as persisting.

Again, a prevalent theme in the interviews was that early exposure matters. Those who persisted had early and continued access to computing education opportunities, 10 of the 26 interviews specifically mention access and exposure. Some of the non-persisters had little (e.g. one computer class in high school) or no computing classes at all. Other women commented on how their chosen field was more readily accessible and offered greater opportunity to succeed. For example, one woman expressed how she was "too engaged" in her International Baccalaureate science classes to even notice what access, if any, she had to computing. One biology major stated that her only option for computing was an elective:

> I wanted to do computer science because that would be my next elective choice. However, by that time it was already booked by the other students. So I think [. . .] I don't know what I chose after that. But had I taken that course I might have changed my career path [. . .]. But I didn't get that head start and I felt that I would have been behind in computer science and it wasn't enough to turn me as I already had an initial interest in biology.

Others shared their concerns about being "behind" in computer science compared to peers with more experience. For example, a finances major told us, "There just wasn't really very much open to me. And I think I might have chosen a career more in that area had I had more opportunities when I was younger. My first experience was computer science at a high school level". She compared her experience to women in the AiC awardee community with whom she did not believe she could compete:

> I mean they've probably computed before they spoke their first word! I mean, that's you know, an exaggeration, but they've been doing it forever [. . .] that just wasn't something that was in my high school.

This second set of interviews provided further evidence that multiple factors enable and hinder women's persistence. For example, having family support and positive role models support persistence while lacking in either hinders persistence. Interest and self-efficacy impact how women understand themselves in relation to coding. For example, one woman chose Web design over coding because, "I hated coding! I hated every second of it. Like coding and me just did not get along". Another IT help desk worker said, "I couldn't understand like what coding was, like how it all came about just because there was, again, if you missed a comma or a period like the whole thing could not work". One last notable finding is that women did express their concern with being a woman in a male-dominated profession. For example, several women shared they were the only women in their computer science class, or that they felt their teacher was sexist: "It was like being a girl in a boy's club".

Comparing quantitative and qualitative findings

An initial take-away from comparing the quantitative and qualitative findings is that early exposure and access matter for persistence. Although the quantitative and qualitative findings are consistent, we ought to consider what the qualitative findings bring to bear on the quantitative survey, lest we conclude that solving problems of exposure and access will remedy all issues of equity.

The quantitative findings suggest that young women who are involved with the more technical aspects of computing have a greater chance of pursing both CS and other tech-related majors in college. It is important to note two limitations to this finding. First, we have not ruled out that exposure to non-technical aspects of computing may contribute to young women ultimately choosing to engage in more technical aspects of computing. Second, we have no evidence regarding the ways in which computational thinking is valued in the daily lives of those women we classify as non-persisters. From a socio-critical literacy perspective, we ought to value the choices women make in self-determining their lives (Gutiérrez, 2008). Additionally, we need to value those who are contributing to the success of others, such as the woman who became a technology teacher for K-8 students. As she said, "They needed someone. There aren't a lot of people who are interested in teaching in grade school who also know stuff about computer science".

Our interview and focus group data remind us that teaching and learning in STEM is a historicized and relational practice (DiGiacomo and Gutiérrez, 2016). Computing has been seen as a white, male discipline and this is not easily ignored nor rectified. We heard stories of a computing teacher who "was so disrespectful to women. He just always feels like their opinions are wrong and doesn't pay attention to them". One young woman told us:

> What I experienced of the field in computer science in general, turned out to be a very, like, straight man's field. I am not straight, I am not a man. So, it was very awkward for me to be in that environment.

Women of color are confronted with additional obstacles, such as a Hispanic woman who felt she always needed to "prove" herself in her computing experiences in ways her white peers did not.

Creating access to computing alone does not ensure that these opportunities do not act as "gate-keepers" to more advanced opportunities. Women expressed how introductory classes in particular are often designed to weed out weaker students, presenting a challenge she called "traumatic". Describing her own experience, one woman said:

> A lot of times in engineering they would skip all of the foundational stuff that maybe I really needed to go over and they would go right into the more difficult stuff that I already knew I couldn't understand [. . .].it moved very quickly.

It is important to remember that access and preparation are not the same thing.

Discussion and conclusion

At one level, our findings are neither novel nor unexpected in that they mirror many of the findings from the previous research discussed above including access, support, and bias. On the other hand, our findings are unique given both the sample size and longevity of the research. Longitudinal research on women's interest and persistence in computing is sparse. This is due in part to the fact that the CS-for-all-initiative is relatively new, so before, many women's early computing experiences were in informal settings that present challenges to following-up with students. Given the national presence of NCWIT, we were in a privileged position of having access to hundreds of women allowing us to make claims from a larger, more diverse population than smaller studies.

Comparing across the qualitative and quantitative data, it is evident that several factors influence persistence in computing, but common to both is that early programming opportunities are significant factors in supporting persistence. This is consistent with other research on access and exposure (Google, 2014), as well as prior work that studied middle-school girls' persistence over time (Friend, 2016). Although we do not want to diminish the importance of other factors such as peer and family support, or how compounded factors work together to support or hinder persistence as in Joan and Sophia's cases (DuBow *et al.*, 2017), we believe this finding is compelling to focus on for several reasons. The most important reason is that among the multiple factors we identified, creating opportunities for women to engage in programming is something that educators have the power to control and commit. Unlike social supports, or contextual factors such as poverty, minority status, or geographic location, educators and policymakers can have great influence in the lives of all students by establishing computing as compulsory across the K12 curriculum. Although this would not be without its challenges, before we discuss those challenges, we present three ways in which compulsory coding potentially would have impacted the women in our studies.

First, if all students were required to engage in computational literacy courses in the same way all students are required to take English and Math classes for example, girls and boys would be equally represented in computer science classes. So, women in our study who were the "lone" female in class would not be subjected to this same experience. However, we know that women are underrepresented in other STEM disciplines beyond computing and as they progress in their education and careers, the "leaky pipeline" results in fewer women than men. While K12 educators cannot control college environments and thus women's persistence over time, we can establish a level playing field from which all students can start, and from there, continue to investigate the causes and factors that lead to attrition.

Second, if we establish a baseline criterion for all students to meet with respect to computational literacy, we can begin to equalize students' experiences toward this criterion. As our qualitative results showed, some women felt "behind" compared to their peers because they did not have the same level of access to computing experiences. We know that currently there is no federal policy dictating the minimum requirements for high school graduation and that it varies from state to state (and in some cases from district to district) (US Department of Education, National Center for Education Statistics, 2008), as only 15 states have policies to provide CS education to high school students and only 6 states provide access to K-12 students (Code.org, 2018). Rectifying this imbalance would alleviate the situation where women lamented that classes were unavailable.

A reasonable objection to implementing compulsory coding in K12 schools is that by merely providing access, it does not follow that interest will increase. Although this argument is not without merit, the same argument is not made with other disciplinary domains such as math or literacy. It does not follow that as not all students will become mathematicians, not all students need a basic level of math understanding. When it comes to persistence, our survey results demonstrate that interest is not a better predictor than access to early programming experiences. Furthermore, early programming experience leads to not only greater persistence in computing fields specifically, but other technology fields as well. Therefore, while interest in programming specifically may not increase with access to programming, a greater sense of identification with the community of computing is likely to occur. We argue this is what occurred for several of the women who were no longer persisting in the narrow definition of computing but were successful in technology or teaching fields. For example, the majority of women in our study who said, "coding and me did not get along" or "I didn't like coding" ended up pursuing other technology majors such as computer graphic design. The third reason for compulsory coding is that it opens up the opportunity for students to define themselves in relation to this way of thinking and their broader place in the world in similar ways to how developing socio-critical literacy skills empowers students to define what is meaningful and significant in their lives.

Our perspective entails that computational literacy should not be considered simply as a means to an end resulting in a coding or a software engineering job. Rather, we ought to acknowledge both the different ways in which computational skills play a role in individuals' lives and individuals' rights to determine what constitutes socially valued outcomes for such literacy. Although Obama invoked "job-readiness" in his call for CS-for-All, he did not prescribe particular career paths and instead connected computer science to multiple professions including teaching, professional football, car mechanics, and nursing (2013, 2016). From an equity perspective, compulsory coding would support not only women's persistence in computing and technology as our data suggest but it could also empower all students to envision themselves as makers, creators, and innovators of their futures. Approaches to teaching and learning computational literacy should accommodate such visions if we truly want to implement CS-for-All.

To be clear, we are not advocating for a sterile implementation of a programming or one-size-fits-all computational literacy curriculum. As critical educators we believe that all learning and schooling takes place in broader societal contexts with challenging structural inequalities, and if we do not take this into consideration, disparities in achievement will persist. Our findings corroborated that structural factors matter. They also highlighted how it may take only one "sexist" teacher to turn a woman away from pursuing CS. With this is mind, we should build on the work that has begun to look explicitly at how equity emerges in CS classrooms (Fields and Enyedy, 2013; Lewis and Shah, 2015) and models for equitable CS education (Vakil, 2018). We should encourage teacher education programs to support equitable learning practices (Darling-Hammond, 2008) and address the shortage of qualified CS teachers (Ladner and Israel, 2016). Finally, we can look to other disciplines that grapple with similar access and achievement problems such as mathematics education (Lubienski, 2008), and explore how to make disciplinary practices meaningful in students' lives (Moll *et al.*, 1992) and encourage disciplinary engagement (Nasir and Hand, 2008).

To ameliorate the complex problem of women's underrepresentation and lack of persistence in computing, we must have complex solutions that embrace the totality of what CS-for-All entails. As the CS-for-All initiative gains traction, we will have more opportunity to investigate how best to support women's persistence and look specifically at how early coding opportunities contribute not only to women's persistence in computing and technologies fields, but also how these opportunities help to foster critical computational literacy in other areas of all students' lives beyond their career choice. Until then, we must recognize our role as researchers, educators, and policy-makers in making equity in computing possible.

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