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The Underrepresentation of Women in Computing Fields: A Synthesis of Literature Using a Life Course Perspective

Joyce B. Main and Corey Schimpf

Abstract—**Using a life course perspective, this literature review synthesizes research on women's underrepresentation in computing fields across four life stages: 1) pre-high school; 2) high school; 3) college major choice and persistence; and 4) post-baccalaureate employment. Issues associated with access to, and use of, computing resources at the pre-high school and high school levels are associated with gender differences in interest and attitudes toward computing. At the college level, environmental context (classroom design, interactions with peers and role models, signals from stereotypical images) contribute to whether students will major in computing, whereas psychosocial factors (e.g., sense of belonging and self-efficacy) and departmental culture play a role in persistence in computing fields. As in other fields, issues associated with work-life conflict, occupational culture, and mentoring/networking opportunities play a role in women's participation in the computing workforce. Several initiatives and programs have been implemented to address women's underrepresentation in computing fields. While great strides have been made in making computing more accessible, the life course perspective highlights the importance of longitudinal studies in identifying students' pathways to and through computing fields, as well as how interventions across life stages may intersect or cumulate to generate trends in computing participation.**

Index Terms—**Computer engineering, computer science, diversity, girls, persistence, underrepresentation, women.**

I. Introduction

Although the proportions of Bachelor's degrees awarded to women in many Science, Technology, Engineering, and Mathematics (STEM) fields have remained relatively constant or have increased slightly over the past 20 years, the computing field has shown a decrease from 28% women in 2001 to 18% women in 2012 [1], [2]. Likewise, women's representation in the computing workforce has decreased dramatically from 36% in 1991 to 25% in 2015 [3]. Given the growing demand for a larger technological workforce and the benefits of diversity to innovation, it is critical to increase the participation of women in computing fields. This literature review uses a life course approach to examine the causes and consequences of the underrepresentation of women in computing fields. Life course perspective is a framework that uses a holistic lens to analyze some population across stages of their life in regards to some phenomenon [4]–[6]. Extending previous reviews [7]–[10], this study synthesizes articles that cover the life span extending across pre-high school, high school, college, and employment. It can therefore identify recurring themes across life stages, uncover new areas for further research, and inform strategic interventions to increase diversity in computing fields. Importantly, the life course perspective can help demonstrate how institutional programs/practices and potential challenges at each life stage converge to produce the current patterns of women's underrepresentation in the computing workforce.

The life course perspective provides a framework for examining the trajectories of individuals within the larger social context and history, as well as insights into individual choices, timing of events, and social networks/influences [4]–[6], [11]–[13]. It highlights the importance of cultural dimensions, and the ways in which social context and practices influence the experiences of girls and women in computing fields. Further, this literature review integrates data from the National Science Foundation, the Computer Science Teacher Association, and the Bureau of Labor Statistics to demonstrate the larger-scale patterns of women's participation in computing.

II. Methods

This review was conducted using multiple approaches to identify articles focusing on research on girls and women in computing fields. The Association for Computing Machinery (ACM) and IEEE Xplore databases were used to find articles with the search terms "girls," "women," and "gender." An additional search was conducted using several select journals with a focus on gender and science and engineering fields, including the *Journal of Women and Minorities in Science and Engineering; Sex Roles: A Journal of Research*; and the *International Journal of Gender, Science and Technology*. Terms used for this search were "girls," "women," "gender," "computing," and/or "computer." These

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J. B. Main is with the School of Engineering Education, Purdue University, West Lafayette, IN 47907 USA (e-mail: jmain@purdue.edu).

C. Schimpf is with Concord Consortium, Concord, MA 01742 USA (e-mail: cschimpf@concord.org).

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TABLE I
NUMBER OF ARTICLES BY LIFE STAGE

Life Stage	Number of Articles
Pre-High School	14
High School	9
College Major Choice	5
College Persistence	17
Post-Baccalaureate Employment	14
Total	**59**

initial broad approaches generated over 2,500 individual articles that were filtered using the stricter inclusion criteria of: (1) appearing in a peer-reviewed journal or conference proceeding between 2000 and 2015; (2) reporting research on education or employment specifically in a computing field defined as computer engineering, information systems, computer graphics, human-computer interaction, or Web development; and (3) focusing on girls or women in computing fields in the United States or Canada as study populations. While there are a number of articles that examine the underrepresentation of women in STEM fields, this review is limited to articles that focus solely on computing fields. After filtering, the reference section of each selected article was examined to identify additional articles that meet the criteria for inclusion in the study.

This extended filtering process yielded 59 articles, which were categorized by the life stage of the sample participants: pre-high school, high school, college major choice, college persistence, or post-baccalaureate employment. Table I summarizes the number of papers included in this review by life stage. Significant findings and emergent themes were identified from each article using thematic analysis. In line with the life course perspective as a theoretical framework, the resulting themes were synthesized by life stage [4]–[6]. Additionally, van Dijk's conception of the "digital divide" was used to contextualize the findings on girls and computing at the pre-high school level [14]. To provide additional context and statistics on the participation of girls and women in computing fields, this review also presents data obtained from published reports generated by the National Science Foundation, the Computer Science Teacher Association, and the Bureau of Labor Statistics. Altogether, 97 references, including journal articles, theoretical and conceptual papers, and data sources were examined.

III. SYNTHESIS OF LITERATURE: THEMES OF UNDERREPRESENTATION BY LIFE STAGE

Table II shows the emergent themes pertaining to the participation of women in computing fields derived from the literature review by life stage: (*A*) pre-high school (preschool to middle school); (*B*) high school; (*C*) college major choice and persistence; and (*D*) post-baccalaureate employment. The sections that follow discuss the themes by life stage more fully.

A. Pre-High School

Issues associated with the "digital divide" are prevalent in the articles focusing on gender and computing at the pre-high school level. While "digital divide" originally referred to the divide between people with and without direct access to a computer [15], the proliferation of computers in schools, households, libraries, and other venues has led researchers to address other factors related to access [14], [16]–[18]. Van Dijk and Hacker [14] developed a four-part scheme to describe these factors: (1) *psychological access*—differences in desire/interest to use computers; (2) *material or direct access* to computers; (3) *skills access*—differences in computing skills across groups; and (4) *usage access*—frequency of use in specific ways (e.g., basic vs. more complex uses).

Psychological access—Based on a sample of 60 boys and 60 girls ranging from 5 to 13 years old, Cherney and London [19] found girls and boys had different preferences for leisure activities. While boys favor computer games, girls favor television. Cherney and London suggest that these differences in leisure preferences may provide different opportunities for potentially developing computer-related skills. Similarly, Cotten *et al.* [20] found that middle school girls are likely to spend more time communicating over media and listening to music, whereas middle school boys spend more time playing with gaming systems. In a study of educational software designed for preschoolers, Sheldon [21] determined that male characters outnumber female characters and suggests that this inequitable visibility may play a role in girls' levels of interest in computing.

Material access—Cotten *et al.* [20] also found that 96% of boys and 81% of girls in middle school owned a game system. Video/computer games are often seen as a common entry route into computing fields [22], [23]; however, there are multiple ways in which games can help develop interest and skills in computing [9], [21], [24], [25]. Cherney [26] and Terlecki and Newcombe [27], for example, indicate that playing video/computer games can help improve mental rotation abilities important to game development and computer graphic design. Insofar as playing games is tied to computing interest, and material access is indicative of frequency of playing games, differences in material access to video/computer games may play a role in the differential participation of women in computing fields.

Skills access—In a qualitative study of mixed teams of girls and boys in the 5th and 6th grades, Ching *et al.* [28] found that boys tended to participate in more complex computer tasks, such as programming, whereas girls more frequently recorded team notes. The authors suggest that this uneven task distribution may lead to uneven development of computing skills. However, interventions, such as instituting fixed schedules for conducting different tasks among team members, can alleviate the uneven task distribution.

Usage access—Willoughby *et al.* [29] examined the dynamics of mixed gender teams of preschoolers and 5th and 6th graders working on age-appropriate computing tasks. They found that in preschool, girls dominated computer use, but among 5th and 6th graders, boys dominated computer use. Investigating a MOOC (a massive online community), Fields *et al.* [30] developed profiles for how boys and girls (approx. 11–18 years old) used *Scratch*, which enables users

TABLE II
COMMON RESEARCH THEMES FOR WOMEN AND GIRLS IN COMPUTING BY LIFE COURSE STAGE

Stage	Theme	Articles	Stage	Theme	Articles
Pre-high school	"Digital divide"—gaps in access, use, and skills	Bain and Rice, 2006; Cherney, 2008; Cherney and London, 2006; Ching, Kafai, and Marshall, 2000; Cotten, Shank, and Anderson, 2014; Fields, Giang, and Kafai, 2014; Sheldon, 2004; Terlecki and Newcombe, 2005; Willoughby, Wood, Desjarlais, Williams, Leacy, and Sedore, 2009	College Persistence	Self-efficacy/ Belonging	Appianing and Van Eck, 2015; Beyer, Rynes, Perrault, Hay, and Haller, 2003; Beyer and Haller, 2006; Beyer, 2014; Huffman, Whetten, and Huffman, 2013; Lopez, Zhang, and Lopez, 2008; Redmond, Evans, and Sahami, 2013; Rosson, Carroll, and Sinha, 2011; Wilson, Bates, Scott, Painter and Shaffer, 2015
	Middle school computing interventions	Baytak and Land, 2010; Robinson and Pérez-Quiñones, 2014; Webb and Rosson, 2011; Werner, Campe, and Denner, 2005, Hulsey, Pence, and Dodges 2014		Work–Life conflict	Armstrong, Riemenschneider, Allen, and Reid, 2007; Armstrong and Riemenschneider Reid and Nelms, 2011; Armstrong and Riemenschneider, 2014; Quesenberry, 2006; Riemenschneider, Armstrong, Allen, and Reid, 2006; Trauth, Quesenberry, and Huang, 2009; Wardell, Sawyer, Mitory, and Reagor, 2006
High School	Differences in course taking and career outlooks	Carter, 2006; Dahlberg, Barnes, Buch, and Rorrer, 2011; Freeman et al., 2014; Gannod, Burge, McIe, Doyle and Davis, 2014; Goode and Margolis, 2011; Guzdial, Ericson, Mcklin, and Engelman, 2014; Kelly, Dampier, and Carr, 2013; Sands, Evans, and Blank, 2010; Weisgram and Bigler, 2006	Post-Graduation Employment	Culture: Norm of pervasiveness	Guzman et al., 2004; Guzman and Stanton 2008; Guzman, Stam and Stanton, 2008; Quesenberry and Trauth, 2007
College Major Choice	Effects of stereotypical images	Cheryan, Plaut, Davies, and Steele, 2009; Cheryan and Plaut, 2010; Cheryan, Meltzoff, and Kim, 2011; Cheryan, Drury, and Vichayapai, 2013; Cheryan, Plaut, Handron, and Hudson, 2013		Mentoring/ Networking	Trauth, Quesenberry, and Yeo, 2008; Trauth, Quesenberry, and Huang, 2009; Windeler and Riemenschneider, 2013
College Persistence	Hierarchical culture	Barker, 2009; Garvin-Doxas and Barker, 2004; Crenshaw, Wolf Chambers, Metcalf, and Thakker, 2008; Garvin-Doxas and Barker, 2004; Larsen and Stubbs, 2005; Margolis and Fisher, 2002; Powell, 2008; Varma, 2009			

to design and share game, story, or animation computer programs. They report that the boys used the platform and participated in the informal computing community to a greater extent than did girls. Bain and Rice [31] did not find statistically significant differences in attitudes, perceptions, or use of computers between girls and boys in the 6th grade; their

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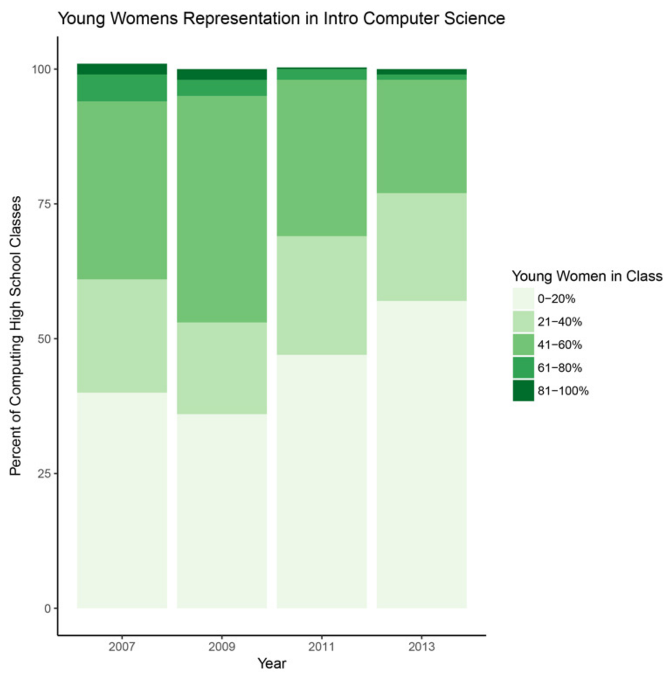

Fig. 1. Proportion of introductory CS classes with different levels of female representation.

qualitative data revealed that girls spend more time on computers. They observed that girls spend more time on instant messenger or completing their homework assignments on the computer, whereas boys spend relatively more time playing computer games.

B. High School

At the high school level, most studies of differences between male and female adolescents in regard to computing focus on course-taking behavior or relative knowledge of careers in computing fields. In addition to the variation across U.S. high schools in the number and levels of computer science (CS) courses offered, there is variation within schools in regard to who enrolls in the CS courses. Using a series of bi-annual national studies from 2005 through 2013, the Computer Science Teachers Association (CSTA) found that fewer than 50% of the high schools surveyed offered Advanced Placement Computer Science classes [32]. Further, CSTA showed that over the years, a smaller proportion of female students are taking an introductory CS course in high school. Fig. 1 illustrates the changes in the proportion of young women enrolled in high school CS courses between 2007 and 2013 [32]. As the color gradient intensifies, the proportion of female students enrolled in CS courses increases (e.g., lightest shade = 0–20% and darkest shade = 81–100%). In 2013, over 75% of the high school CS courses in the sample enrolled 0–40% female students. Between 2007 and 2013, the percentage of introductory CS classes with 0–20% female students increased. Meanwhile, the percentage of high school classes with 41–60% female students decreased in the same time period. The CSTA data are consistent with previous literature that show that, on average, women enter college with less computing experience than men have [10], [33], [34].

The widening gap in the proportion of female high school students taking introductory CS courses has important implications for college major choice. In addition to showing that male high school students reported more CS-related activities and courses than did female high school students, Carter [33] also found that both female and male students indicated that they did not intend to pursue a computer science major in college, due to their preference for other majors and lack of desire to work at a computer all day. Carter also indicated that 80% of the survey respondents were largely unaware of the topics a CS undergraduate course would address. Based on interviews with 20 female high school students participating in the Women in Cyber Security summer residential program, Kelly *et al.* [35] found that girls had little information about computing careers, but that they were aware of issues associated with gender inequities in computing fields.

C. College Major Choice

Previous studies have shown that women's lower participation in computing fields at the college level is related to several psychosocial factors, such as sense of belonging, perceived similarity, achievement motivation (expectancy value theory), and self-efficacy [36]–[47]. Stereotypical images, classroom environments, and interactions with peers and others in computing fields create contexts that appear to influence women's relative interest in pursuing computing related majors. In a series of studies [36], [37], [39], [40], Cheryan and her colleagues demonstrated the effects of stereotypical images and environments on the likelihood that women will choose to major in CS. Their manipulation of computer science classrooms to depict more stereotypical images of computer science (e.g., video games) resulted in women having less interest in the environment, whereas more neutral classroom environments (e.g., nature) increased women's interest in computer science to the same level as that of men's [39]. Cheryan *et al.* [37] found similar effects when they tested virtual classroom environments, exposure to media (e.g., fabricated newspaper articles) [40], and interactions with role models depicted as stereotypical [36]. Altogether, these studies suggest that external cues that signal belonging in an environment are critical in determining student interest in a given field and that a lack of perceived similarity [38] with those in computing fields plays a role in women's lower interest in these fields.

Appianing and Van Eck [41] investigated factors that influence women's choice to major in CS using a survey instrument that measures students' perceptions of computer technology fields. Using expectancy-value theory, they found that the value participants associate with the field correlates with choosing a computer technology major, and that women placed less value on computer technology than men. In conjunction with research from Cheryan *et al.* [36], [37], these studies suggest that women are less likely to be interested in, or major in, computing fields.

D. College Persistence in Computing Fields

Among those who choose to major in computing, studies indicate that there are gender disparities in student degree

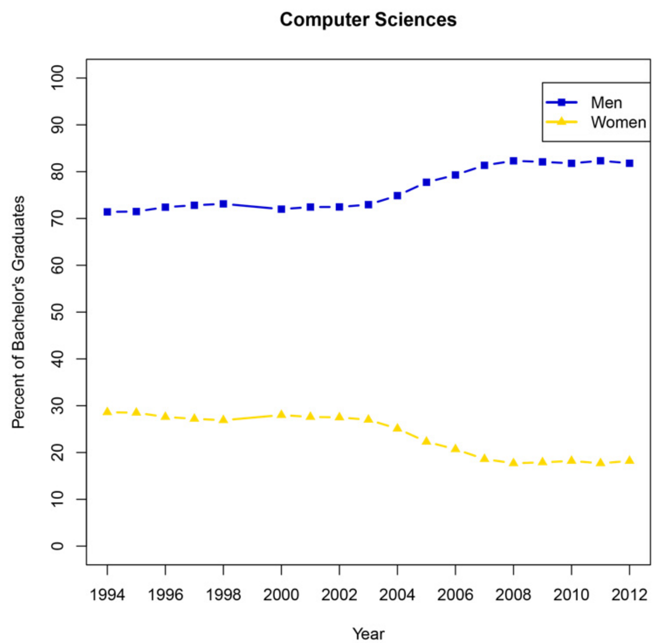

Fig. 2. Computer sciences bachelor's graduates by gender. *Data source: NSF Women, Minorities and Persons with Disabilities in Science and Engineering.*

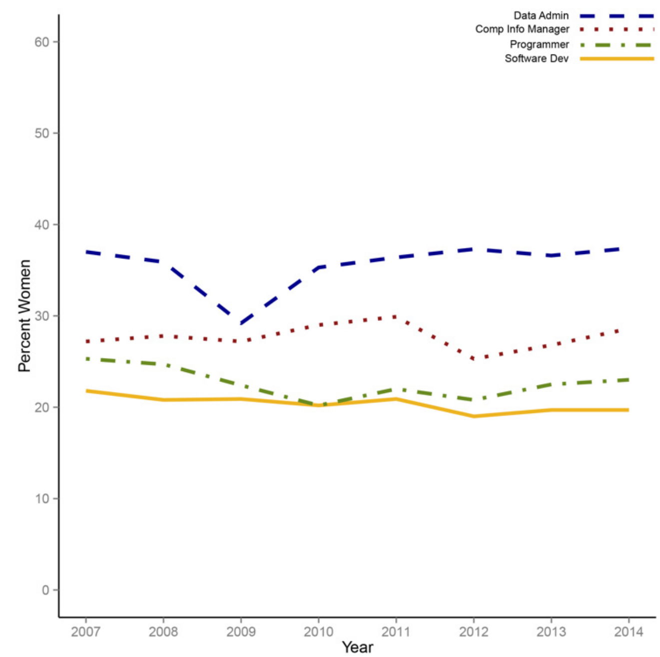

Fig. 3. Percent of women in select computing careers (2007–2014).

completion. For example, in a study of 23 institutions in the state of Virginia between 1992 and 1997, Cohoon [48] showed that female students had a higher attrition rate than male students at 18 of the institutions. Of the remaining five, three had similar attrition rates by gender and two had higher rates among men. Margolis *et al.*'s 2000 study [49] also found higher attrition rates for women in Carnegie Mellon's School of Computer Science. However, continued intervention efforts at the school have resulted in an increase in the proportion of women in computer science—in 2014, 40% of the incoming class of the School of Computer Science were women [50]. But nationally the proportion of women pursuing CS is decreasing. Fig. 2 depicts the proportion of men and women graduating with bachelor's degrees in computer sciences in the United States between 1994 and 2012 [1], [2], [51]. It shows that the proportion of women completing degrees in CS has steadily decreased since 1994.

The lower participation of women in college computing fields has also been associated with the male and stereotypical computer culture as well as variation in computer-related self-efficacy [45]. Self-efficacy is the belief in one's ability to accomplish a given task or achieve a certain goal, and is associated with motivation and behavior [52]. Women's lower levels of computer self-efficacy compared to men is well-documented, and this gender difference is often associated with women's lower participation in computing fields [41]–[47], [53]. For example, in a series of studies in CS, Beyer and colleagues [42], [45], [46] demonstrated that women have lower computer self-efficacy than men. Lopez *et al.* [54] and Redmond *et al.* [55] show that self-confidence is associated with student persistence in CS programs. Researchers have also found that a male-dominant culture in some computing environments appears to play an important role in women's participation in computing majors [56]–[61]. For example, in an ethnographic study of students and instructors in CS courses, Garvin-Doxas and Barker [59] illustrate the existence of an informal student hierarchy and a "defensive climate," where communication is more distant and potentially marginalizing, rather than supportive and inclusive.

E. Post-Baccalaureate Employment

Fig. 3 shows women's lower participation in the U.S. computing labor force based on data from the Bureau of Labor Statistics [62]–[69]. It shows the proportion of women who worked as programmers, software developers, database administrators, or computer information managers between 2007 and 2014. The lower proportion of women in the workforce (roughly 20–40% depending on career category) is consistent with women's participation in computing at the K–12 and college levels. However, according to Wardell *et al.* [70], women are 2.5 times more likely to leave the computing workforce than men. They attribute this to work-family conflicts, the occupational culture of computing fields, and limited mentoring and networking opportunities.

Trauth *et al.* [71]–[73] advanced the theory that differences among individual women in terms of values and motivation partially explain the underrepresentation of women in information technology (IT), moving away from explanations of gender-based differences. For example, among women in IT, there is variation in career anchors, which are self-perceived talents, values, and motives pertaining to careers [74], [75]. This variation in career anchors across individuals has important implications for the selection of and persistence in a given career. Based on a study of 92 IT workers, Quesenberry and Trauth [75] showed that women aligned with technical or managerial competence career anchors, and that a given individual can have multiple career anchors and that these can change over time. They found that the importance of lifestyle integration and focus on work-life balance changes over time as women enter different stages of family formation—women with children tend to focus less on work-life balance as their children get older.

Several studies identified challenges associated with negotiating the competing demands of work and family (work-family conflict) in the retention of women in the computing workforce [76]–[78]. These issues are not necessarily unique to computing fields, but the relatively low numbers of women entering the field may make them particularly salient. Riemenschneider *et al.* [78], for example, found that family responsibilities were strongly connected to women's decisions to leave work. Further, family responsibilities were direct or indirect barriers to promotion. In a related study of work-family conflict, Armstrong *et al.* [77] found that women are more likely to attribute stress to work responsibilities than family responsibilities. The authors surmise that this may reflect the nature of IT work, which requires continual learning and, consequently, work-related stress. The 39 women in their sample who worked at Fortune 500 organizations reported that having a flexible work schedule reduced their stress by enabling them to respond to family emergencies. However, this flexibility also meant that they had to be available to work at night or on weekends, which can complicate work-family balance in other ways [79], [80].

Studies by Guzman and colleagues [81]–[83] identified a distinct occupational culture among information technology professionals within organizations. Occupational culture refers to the ways of thinking and the symbols and language shared by people in a similar work field [81], [82]. Some of the characteristics of this particular occupational culture include "*extreme and unusual demands pertaining to working in the profession, particularly relating to long hours, and the need for constant self re-education as a form of intra-group bonding*" and "*maintaining boundaries between groups, and excluding out-group members*" [81, p. 45]. Guzman and Stanton [83] found a difference between men and women in the measure of Pervasiveness, which is the relative degree that IT is integrated into leisure activities. Men are more likely to have higher Pervasiveness scores than women, and this score is associated with affective commitment to their work. This set of studies, however, is based on interviews and is therefore not broadly generalizable.

Studies also show that women have fewer mentoring/networking opportunities in IT than men [76], [84]. Trauth *et al.* [84], for example, found that women in IT felt excluded from social networking activities, such as golfing, and therefore from opportunities for potential career advancement. Both female and male IT professionals who receive career mentoring express greater occupational commitment [76]. Windeler and Riemenschneider [85] examined how different forms of mentoring and interaction with one's supervisor affected workplace commitment among IT workers. They found that women who received career mentoring focusing on developing and enhancing their careers had a stronger commitment to their organization. Thus, access to career mentoring and networking activities have the potential to improve the retention of women in the IT workforce.

IV. Interventions

While this literature review identified the likely causes and consequences of the underrepresentation of women in computing fields, there are also several efforts to address and alleviate these gender inequities at the pre-high school, high school, and college levels. Many of the interventions designed for middle school populations aim to increase girls' interest in and/or knowledge of computing [22], [86]–[89]. For example, there have been important efforts to engage middle school girls in Alice programming software or Macromedia Flash to create interactive stories [86], games [87], [88] or interfaces [89]. Although the results of some of these interventions were mixed [86], [88], [89], they endeavored to address the differential patterns in access, use, and skill development among young students.

Similarly, at the high school level, many of the interventions were designed to increase computing related knowledge or interest [35], [90]–[96]. One of the most ambitious projects, Georgia Computes!, was implemented for six years in the state of Georgia [92]. This project reached female, African American, and Hispanic students in grades 4–12 through after school and weekend programs and summer camps. Generally, many of these interventions reported positive gains in young women's interest in or attitude toward computing [90], [94] and computing classes [92], although some also noted mixed results [92], [95]. For example, students who attended Georgia Computes! summer camps demonstrated significant gains on their post-intervention statements regarding whether they liked computing, were good at it, and were good at computing compared to their friends. Furthermore, comparing the 2006 and 2012 Georgia Computes! cohorts, there was a 237% increase in the number of young women taking the computer science advanced placement exam (CS AP).

Building on these previous intervention efforts and the research on the underrepresentation of women in computing, the White House, the U.S. Department of Education, and the National Science Foundation have launched a joint initiative—CS for All—devoted to offering educational opportunities to all U.S. students in computer science [96]. This initiative cements the importance of increasing the participation of students from all backgrounds in computing fields. In an increasingly technology driven world and a rapidly changing economic environment, diversifying the computing workforce and providing opportunities for all students to access computing is crucial. The life course perspective, illustrates the factors that influence women's likelihood of entering computing fields across the life stages from pre-high school through post-baccalaureate employment. Thus, it is critical to consider the long-term effects of interventions, and to consider intervention designs that have the potential to address issues across the life stages, as well as the potential to translate to computing workforce development.

V. Conclusion

This literature review applied the life course perspective to examine the underrepresentation of women in computing across four life stages: (1) pre-high school (preschool to middle school); (2) high school; (3) college major choice and persistence; and (4) post-baccalaureate employment. At the pre-high school level, the four factors related to the "digital divide"—psychological, material, skill, and usage—provided a framework for identifying potential sources of the gender differences in interest in computing fields. At the high school level, a number of studies established differences in course taking behavior and knowledge regarding careers in computing fields between male and female adolescents. Women are less likely to major in computing fields at the college level due to classroom environments, stereotypical images and messages, and individual interactions that reduce women's sense of belonging. Other psychosocial factors, such as perceived similarity, achievement motivation, and self-efficacy also play a role in women's likelihood of majoring in computing. Women represent only 20–40% of the professionals in computing fields, and they are more likely to leave the profession due to work-family conflict, the pervasive occupational culture, and lack of mentoring and networking opportunities.

Several programs, initiatives, and interventions have been launched to address women's underrepresentation in computing fields. At the pre-college level, strategies often include providing girls with engaging hands-on experiences, increasing motivation to pursue computing through emphasizing the social impact of computing work, introducing girls to positive role models, and providing information to teachers and key individuals to encourage greater interest in computing and technology. At the college level, interventions tend to be comprised of redesign of introductory CS courses to emphasize applications or to include teaming, changes in course requirements that provide access to a greater number of students to computing skills, strengthening mentoring programs, and encouraging women's participation in conferences and other professional development opportunities.

While great strides have been made in making computing more accessible to students from diverse backgrounds, the life course perspective highlights the importance of conducting longitudinal studies to identify students' pathways to and through computing fields, and how interventions at multiple life stages may intersect or cumulate to generate trends in computing participation. Further work on students' career decision making and selection of computing professions would also be helpful in translating school-related interventions to increasing the size and diversity of the workforce. The number of factors that influence girls and women's decisions to pursue computing across the life stages demonstrate the need for multiple stakeholders, such as K-12 teachers, families, university faculty, university computing programs, academic institutions, and the government, to work together to generate positive change in diversifying computing at all levels.

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Joyce B. Main received the Ed.M. in administration, planning, and social policy from the Harvard Graduate School of Education, and the Ph.D. degree in learning, teaching, and social policy from Cornell University. She is an Assistant Professor of engineering education with Purdue University. She uses quantitative and qualitative research methods to examine engineering students' academic pathways and transition to professional engineering practice. She was a recipient of the 2014 American Society for Engineering Education Educational Research Methods Apprentice Faculty Award, the 2015 Frontiers in Education Faculty Fellow Award, and the National Science Foundation Faculty Early Career Development Program (CAREER) Award in 2017.

Corey Schimpf received the Ph.D. degree in engineering education from Purdue University where his dissertation research explored the use of Minecraft to teach early engineering college students about the design process. He is a Learning Analytics Scientist with the non-for-profit Concord Consortium, which develops technology and curriculum for STEM learning in K–12. Two major strands of his work revolve around learning analytics/educational data mining and the underrepresentation of women and minorities in STEM fields. In the first strand, his work focuses on the development and analysis of learning analytics that model students' cognitive states or strategies from fine-grained computer-logged data of students' participation in open-ended science and engineering projects as well as assistive software for researchers engaged in these methods. In the second strand of work, he examines the effects of policies on underrepresentation and patterns in retention and attrition in STEM fields for underrepresented groups.