# Strengthening the Computing Research Pipeline through Minority Participation:

## The Case for Undergraduate Research Experiences

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***Abstract*—There is growing concern about the supply of computing graduates who intend to pursue research careers. A pool of talent from which future computing research professionals could be drawn are underrepresented racial-ethnic minority (REM) students (i.e., African Americans and Hispanics), who comprise a growing share of the college-age population but are disproportionately represented at higher levels of the computing research pipeline. This paper explores how undergraduate research experiences may improve the graduate degree intentions of computing undergraduates. Findings suggest that minority status is positively related to an increased likelihood of pursuing a graduate degree in computing among all students, and this association is strongest for REM students. Further analyses reveal that psychosocial skills attained through undergraduate research explain this relationship. These results contribute to the growing literature that seeks to identify which contexts and interventions are effective in improving REM students' intentions for graduate study and capacity for research careers.***

***Keywords*—minority students; graduate degree intentions; undergraduate research experiences; computing research pipeline; psychosocial skills and behaviors***

## I. INTRODUCTION

The need for highly skilled computer and information research professionals will grow ever more important as technological innovation continues to become further intergraded into daily life. In fact, the Bureau of Labor Statistics [1] projects a 15% growth in demand for computer and information research scientists between 2012 and 2022. Despite this demand, the United States is not producing enough professionals to fill these positions [1]. In order to meet the demands of the national marketplace and to ensure that the United States' computing enterprise remains internationally competitive, it is essential that the supply of postsecondary computer science graduates who are prepared for high quality, research-intensive employment be improved and strengthened.

One way to improve the supply of talented computing[1] postgraduates who are capable of pursuing research careers is to increase the participation of underrepresented racial-ethnic minority[2,3] (REM) students in computing disciplines. In 2012, it was estimated that REM students earned 23% of the computing degrees at the bachelor's level and 9% of the computing degrees at the doctoral level but constituted about 40% of the American college-age population[4] in the same year [5] [2]. Given that REM college students are a strong pool of potential recruits to the computing research workforce, it is important to understand factors affecting REM college students' persistence in computing-related fields and careers.

This paper contributes to the literature that seeks to understand which contexts and interventions are particularly effective in improving REM students' intentions for graduate study and capacity for research careers in computing-related disciplines. Given the importance of research experience in training future scholars in science, technology, engineering, and mathematics (STEM) fields, this study aims to identify how undergraduate research programs influence students' perceptions of their academic and career ability and intentions for graduate study.

## II. UNDERGRADUATE RESEARCH ENGAGEMENT

### *A. A pathway through the science pipeline*

Participation in undergraduate research is widely believed to attract and retain students in the STEM pipeline [3, 4, 5]. Studies have identified a range of benefits to students participating in undergraduate research experience (URE) programs, including the development of technical knowledge and skills [3, 4, 5], enhanced interest in science careers [3, 4, 6, 7], and the development of academic and professional self-confidence [3, 4, 5, 6, 7, 8]. The most notable and consistent finding of these studies is that undergraduate research participation is linked to higher educational aspirations in STEM fields [3, 4, 5].

### *B. Undergraduate research and minority student outcomes*

Undergraduate research programs are thought to be especially important for improving the retention of REM

[1] The terms computing and computer science are used interchangeably throughout this paper.
[2] Persons self-identifying as: Hispanic, Latina/o, Black, African American, Native American, or Alaska Native.

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[3] The National Science Foundation defines a minority as a person who identifies themselves as being: Black; Hispanic; American Indian; Alaskan Native; Native Hawaiian; Other Pacific Islander; or Asian) [2]. In this paper, Asians and Asian Americans are not considered underrepresented racial-ethnic minorities because they are well represented in science and technology professions compared to their representation in the national population.
[4] Individuals aged 18 - 24. This calculation does not include students of two or more races or some "other" race. In addition, Hispanics included in this calculation may be of any race.
[5] These calculations only include US Citizens and permanent residents.

students in STEM disciplines. Many studies support this belief [3, 4, 5, 8, 9, 10]. For instance, Lopatto [3, 4] analyzed students' evaluations of summer UREs using the Survey of Undergraduate Research Experiences. He found that minorities (i.e., African Americans, Hispanics) included in the study tended to report higher learning gains from participating in a summer URE compared to White, non-Hispanic students [4]. In another empirical study, Russell, Hancock, & McCullough [5] examined the experiences of approximately 4,500 students who participated in undergraduate research opportunities (URO). Russell et al. [5] found that UROs clarified students' interest in a STEM career and increased students' anticipation of a doctoral degree. Notably, Russell et al. [5] found that the effects of UROs tended to be strongest among Hispanics, and weakest among non-Hispanic whites.

Scholars have also suggested that undergraduate research participation positively influences academic persistence and success by enhancing students' psychosocial competence. Research conducted by Hunter, Laursen, & Seymour [6] supports this claim as they found that undergraduate research participation provides students with an opportunity to master the skills and develop the behaviors (i.e., domain identification, self-confidence, motivation to learn, networking, laboratory experience) they need to be successful in STEM degree programs and careers. Others [4, 6] have found similar results, showing that undergraduate research participation increases students' sense of belonging to the science community and leads to positive changes in students' attitude and confidence toward learning. While all students' psychosocial well-being is likely to benefit from research engagement, prior work indicates that REM students seem to be more sensitive to psychosocial factors associated with academic success and retention [11, 12, 13], such as belonging, self-confidence, and motivation to learn, which are skills and behaviors that students often gain through undergraduate research involvement.

In sum, the literature shows that undergraduate research participation benefits STEM majors in a variety of ways. Among these benefits are: increased STEM career interest, graduate school matriculation, increased motivation to learn, and enhanced knowledge and skills. Moreover, while UREs are beneficial for all students, research suggests that the effects of UREs are greater for REM students compared to racial majorities.

## III. THE CURRENT RESEARCH

Although a great deal of research has shown that minority students underrepresented in STEM fields seem to benefit more from undergraduate research participation than racial majority students, much less research has tried to explain why this relationship exists, and even fewer studies have investigated the mediating role of psychosocial factors in the relationship. The present study addresses these gaps in the literature by developing and testing models that explore the associations among these variables in a cross-sectional study of computing undergraduates. Ultimately, this research aims to increase our understanding of the underlying processes of UREs that are related to students' graduate study intentions while informing the emerging literature on how UREs can help broaden the participation of REM students in computing fields and prepare students from diverse backgrounds for computing research careers.

### *A. Potential mediating factors*

As indicated in section II.B. (Undergraduate research and minority student outcomes), psychosocial skills and behaviors that are attained through undergraduate research participation are thought to influence students' educational intentions and achievement. In the next section, two psychosocial variables are discussed that have been identified in the literature as predictors of academic success and persistence.

#### *1) Self-Efficacy*

Personal beliefs in (or expectations of) one's ability to succeed in a given academic or career domain have been proven to be a consistent predictor of college success, degree attainment, and career aspirations [14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24]. Albert Bandura [17], and Taylor and Betz [24] hypothesized that efficacy beliefs affect student outcomes by improving students' attitude toward learning and career decision-making. Importantly, efficacy beliefs can also influence whether an individual engages in a particular behavior or chooses to complete an activity. Therefore, efficacy beliefs can serve as a mechanism of motivation that can mitigate barriers to academic success (i.e., racial stereotypes, sociocultural and socioeconomic influences) that often deter underrepresented students from persisting in STEM majors or careers. Given that efficacy beliefs tend to predict whether an individual engages in a particular behavior, one goal of the current research is to examine whether positive efficacy beliefs are related to higher intentions to pursue graduate study among undergraduate computing majors.

#### *2) Academic Preparedness*

Academic preparedness (or readiness) has been shown to have a strong association with post-secondary retention and student success [25, 26, 27]. However, much of the research [28, 29] on academic outcomes for students in higher education examines the impact of academic performance or ability (i.e., standardized test scores, grade point averages) on educational attainment. Emerging literature has suggested that non-cognitive indicators of academic preparedness, such as academic tenacity (i.e., students' mindsets about their intelligence); and college knowledge (i.e., students' understanding of the college admission process and requirements for college entry), are important components of academic preparedness and predict academic persistence [30, 31, 32]. The sub-concept of "college knowledge" was operationalized in this study as the extent

to which students felt that their URE improved their knowledge about the graduate admission process, which should be associated with higher intentions for post-baccalaureate study among computing undergraduates.

### B. Hypotheses

This study tested the following hypotheses:

*1)* There are significant positive relationships among the following: minority status, gains in graduate degree intentions, gains in graduate admission knowledge, and gains in self-efficacy;

*2)* REMs will report greater gains in the following compared to racial majorities: (a) graduate degree intentions, (b) graduate admission knowledge, (c) and self-efficacy; and

*3)* Gains in graduate admission knowledge and self-efficacy will mediate the relationship between minority status and gains in graduate degree intentions (both separately (a, b) and in combination (c)).

## IV. METHODS

### A. Sample

Two hundred and twelve undergraduate computing[6] students who had completed a URE[7] during the summer voluntarily participated in this research[8]. Students were recruited during two different semesters (Fall 2011 and Fall 2012) as a part of the Center for Evaluating the Research Pipeline's (CERP) annual data collection. Given that the study's focus is on students who are traditionally underrepresented in computing, the results presented in this paper are from an aggregate dataset that includes two years' worth of data. Aggregating the data in this fashion allowed for a larger sample size and provided enough observations to perform meaningful statistical analyses. Students' demographic characteristics are displayed in Table 1.

### B. Procedure

Students who were majoring in a computing-related field were invited to complete an online survey in Fall 2011 or 2012. Included in the surveys were questions relating to students' demographic background (i.e., race/ethnicity, gender, parents' highest education level); students' perceived gains from research participation (i.e., gains in knowledge, skills, and self-efficacy); and the extent to which students perceived that their URE influenced their graduate degree intentions.

[6] Students were eligible to participate in this research if they were majoring in computer science, computer engineering, computer information systems, or any other computing–related field such as computational biology or digital media.

[7] In the current work, a URE was classified as any of the following: undergraduate research experience at home institution, undergraduate research experience at another institution, or a research internship, but does not include an independent study or a research course.

[8] A total of 4,712 students participated in this study, but 4,500 students were excluded from analyses because they had not declared their major in a computing field, had not participated in a URE, or not all relevant data were available.

*Table 1.* Demographic characteristics of study participants

| | Gender | |
|---|---|---|
| | Male | Female |
| **REM students (n = 31)** | | |
| Black or African American | 15 | 7 |
| Native American or Alaska Native | 2 | -- |
| Hispanic or Latino/a | 6 | 1 |
| **Racial majority students (n = 181)** | | |
| White | 81 | 61 |
| Asian | 15 | 24 |
| **Total N** | 212 | |

### C. Measures

#### *1) Outcome measure: Gains in graduate degree intentions*

Gains in graduate degree intentions were measured by aggregating four items which asked students to indicate how much their URE increased the likelihood that they would accomplish the following: Attend graduate school immediately after finishing your undergraduate degree; Study computing in graduate school; Earn a Master's degree in computing; Earn a PhD in computing. The index was measured on a 5-point Likert scale ranging from (1) Much less likely to (5) Much more likely, with higher scores indicating greater intentions to pursue graduate study in computing. Cronbach's alpha[9] indicated good reliability for the measure ($\alpha = 0.88$).

#### *2) Main predictor measure: Minority status*

Students were instructed to indicate their race or ethnic background by selecting all that apply from the following: American Indian/Alaska Native; Asian (includes Asian Indian, Chinese, Filipino, Japanese, Korean, Vietnamese); Hispanic/Latina/o/Spanish origin (includes Cuban, Mexican, Mexican American, Chicano, Puerto Rican); Black/African American; Native Hawaiian; Pacific Islander (includes Guamanian, Chamorro, Samoan); and White. Race and ethnicity categories were collapsed into two groups for analysis: REMs and racial majorities. REMs refer to students who self-identify as Hispanic, Latina/o, Black, African American, Native American, or Alaska Native, while racial majorities refer to students who self-identify as White or Asian.

#### *3) Mediator measure 1: Gains in graduate admission knowledge*

Gains in graduate admission knowledge were measured by aggregating three items assessing students' increased knowledge in the following areas: Criteria for admission to graduate programs; How to get financial support for graduate school; How to select the right graduate program for you. The index was measured on a 4-point Likert scale ranging from (1) No more than I had (4) Quite a bit more, with higher scores indicating greater gains in graduate admission knowledge. Cronbach's alpha indicated good reliability for the measure ($\alpha = 0.92$).

[9] A statistical test that is used to determine the internal reliability of multi-item measures or constructs.

#### 4) Mediator measure 2: Gains in self-efficacy

Gains in self-efficacy were measured by aggregating five items asking students to indicate how much their URE increased their confidence in the following areas: Complete your undergraduate degree in computing; Get admitted to graduate school in computing, if you choose to; Complete a graduate degree in computing; Become a capable researcher in computing; Have a successful career in computing. The index was measured on a 5-point Likert scale ranging from (1) Decreased a lot to (5) Increased a lot, with higher scores indicating greater gains in self-efficacy. Cronbach's alpha indicated good reliability for the measure ($\alpha = 0.92$).

#### 5) Covariates

Three covariates were included in the analyses: overall graduate point average (GPA), first-generation (FG) status, and prior science exposure [10]. These covariates were included in the analyses because they have been linked to intent to persist in postsecondary education [33, 34, 35, 36]. Therefore, the results reported in the proceeding section are true beyond the effects of the covariates.

## V. RESULTS

### A. Bivariate statistics

To evaluate Hypothesis 1, bivariate statistics were calculated. The results are presented in Table 2. Consistent with the prediction, all correlations were statistically significant (at the 0.05 or 0.01 level) and positive.

*Table 2*. Bivariate correlations of the variables under study

| | (1) | (2) | (3) |
|---|---|---|---|
| (1) Minority status[+] | -- | | |
| (2) Gains in graduate degree intentions | 0.17* | -- | |
| (3) Gains in graduate admission knowledge | 0.23** | 0.45** | -- |
| (4) Gains in self-efficacy | 0.17* | 0.63** | 0.49** |

Results were obtained using the Statistical Package for the Social Sciences. Coefficients were obtained using the Statistical Package for the Social Sciences. Pearson Product (2 tailed) correlations are shown.
[+]Minority status is coded 0 for racial majority students and 1 for REM students. *p < 0.05, **p < 0.01.

### B. Differences between REM and racial majority students

Next, a one-way multivariate analysis of covariance was conducted to examine minority status (racial majority vs. REM) differences in students' gains (Hypotheses 2a – 2c) on the measures under study, while controlling for the covariates. Results showed a statistically significant difference between racial majority and REM students on the combined measures, Pillai's trace = 0.08, $F(3, 205) = 5.81$, $p < 0.01$. See table 3 for the estimated marginal means for the three main variables under study.

*Table 3*. Estimated Marginal Means for the variables under study

| | Racial majority students | REM students |
|---|---|---|
| **Measure** | M(SE) | M(SE) |
| Gains in graduate degree intentions** | 3.24(0.07) | 3.77(0.17) |
| Gains in graduate admission knowledge*** | 1.93(0.07) | 2.71(0.18) |
| Gains in self-efficacy** | 3.64(0.06) | 4.08(0.15) |

Results were obtained using the Statistical Package for the Social Sciences. Means depicted in the table are the means for each variable under study controlling for the covariates. M, Mean; SE, Standard Error. An asterisk connotes a statistically significant difference between racial majority and REM students. *p < 0.05, **p < 0.01, ***p < 0.001.

### C. Explaining the relationship between minority status and graduate degree intentions

A one-way analysis of covariance revealed that the effect of minority status on students' gains in graduate degree intentions, controlling for the covariates, was significant, $F(1, 207) = 8.71$, $p < 0.01$. Next, three mediation models were tested. To test for mediation, Preacher & Hayes' [37] bootstrapping procedure was used with 10,000 resamples and 95% bias-corrected confidence intervals. All analyses were performed in the Statistical Package for the Social Sciences.

#### 1) The role of graduate admission knowledge

To address hypothesis 3a, a single mediator model was tested. The overall model was significant, $F (5, 206) = 11.98$, $p < 0.001$, $R^2 = 0.23$, $\Delta R^2 = 0.17$. As shown in Figure 1 (page 5), the path from minority status to gains in graduate admission knowledge and the path from gains in graduate admission knowledge to gains in graduate degree intentions were statistically different from zero. Further, the indirect relationship between minority status and gains in graduate degree intentions via gains in graduate admission knowledge was significant as indicated by a 95% bootstrapped confidence interval that did not include zero [0.09, 0.47]. Of import, the association between minority status and gains in graduate degree intentions became non-significant after controlling for gains in graduate admission knowledge.

#### 2) The role of self-efficacy

To investigate Hypothesis 3b, another single mediator model was tested. The overall model was significant, $F (5, 206) = 29.17$, $p < 0.001$, $R^2 = 0.41$, $\Delta R^2 = 0.35$. As shown in Figure 2, (page 5) the path from minority status to gains in self-efficacy and the path from gains in self-efficacy to gains in graduate degree intentions were statistically different from zero. Additionally, the indirect relation between minority status and gains in graduate degree intentions via gains in self-efficacy was significant as indicated by a 95% bootstrapped confidence interval that did

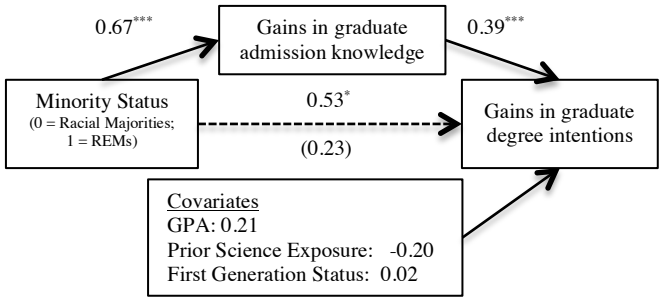
[10] GPA was measured by asking students to indicate their grade point average on a 4.0-point scale. Prior science exposure was measured by asking students to indicate whether they had experienced any of following in high school: A science fair award for a computing project; An AP computer science course; A formal bridge program between high school and college; or an NCWIT award for Aspirations in Computing. Students who indicated "yes" to any of the aforementioned activities were coded as 1 while students who indicated "no" to all of the aforementioned activities were coded as 0. FG status was measured by asking students to indicate their parents' highest education level from the following: Less than high school; High school graduate or GED; Some college; Bachelor's degree; Master's degree; PhD; and Professional degree. Students whose parents' highest education was either less than high school or high school graduate or GED were coded as FG college students while all other students were coded as continuing-generation students.

not include zero [0.07, 0.49]. Notably, the direct association between minority status and gains in graduate degree intentions became non-significant after entering self-efficacy into the model.

*3) The roles of graduate admission knowledge AND self-efficacy*

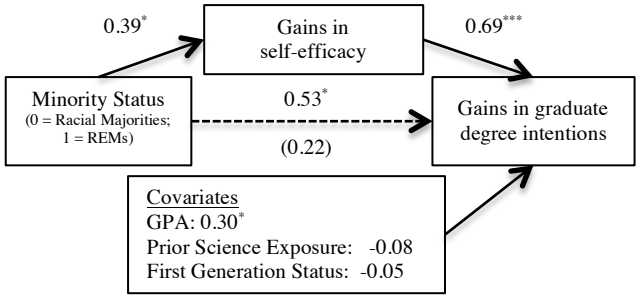
To assess hypothesis 3c, a multiple mediator model was tested. The overall model was significant, $F(6, 205) = 26.54$, $p < 0.001$, $R^2 = 0.44$, $\Delta R^2 = 0.38$. As shown in Figure 3, the paths from minority status to gains in graduate admission knowledge and gains in self-efficacy were both statistically different from zero. In addition, the paths from gains in graduate admission knowledge and gains in self-efficacy to gains in graduate degree intentions were statistically significant. Moreover, the total indirect relationship between minority status and gains in graduate degree intentions through the two mediators was significant as indicated by a 95% bootstrapped confidence interval (total indirect effect) that did not include zero [0.11, 0.60]. Importantly, the direct association between minority status and gains in graduate degree intentions became non-significant after entering the two mediators into the model.

Figure 1. Indirect effects of graduate admission knowledge on REM vs. racial majority students' gains in graduate degree intentions.



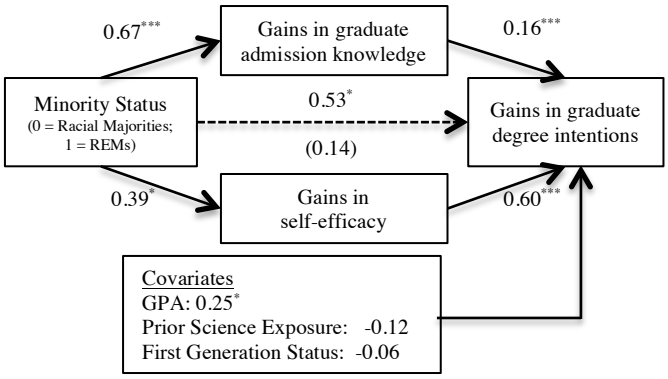

Note. Unstandardized coefficients are shown. Coefficient in parentheses shows the association between minority status and the outcome variable after controlling for graduate admission knowledge. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Figure 2. Indirect effects of self-efficacy on REM vs. racial majority students' gains in graduate degree intentions.




Note. Unstandardized coefficients are shown. Coefficient in parentheses shows the association between minority status and the outcome variable after controlling for self-efficacy. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Figure 3. Indirect effects of self-efficacy and graduate admission knowledge on REM vs. racial majority students' gains in graduate degree intentions.




Note. Unstandardized coefficients are shown. Coefficient in parentheses shows the association between Minority Status and the outcome variable after controlling for graduate admission knowledge and self-efficacy. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

## VI. DISCUSSION & FUTURE DIRECTIONS

At present, there is a high demand for computing research professionals with post-baccalaureate degrees; however, the current production of graduates is insufficient to meet this demand [1]. REMs make up roughly 40% of the American college-age population but they earn only a fraction of the degrees awarded in computer science [2]. Given that REM students represent a potential source of labor for the computing research workforce, the current work sought to determine if and how UREs influence REM students' graduate degree intentions and, ultimately, research career intentions.

The present findings suggest that minority status is a predictor of psychosocial outcomes and graduate degree intentions among computing undergraduates who have participated in an undergraduate research program. However, consistent with extant research on the effects of UREs on underrepresented populations, it was found that REM students reported significantly higher gains in graduate degree intentions relative to racial majorities after participating in a URE [3, 4, 5, 9]. Compared to racial majority students, REM students included in the study also reported higher perceived gains in graduate admission knowledge and self-efficacy from their involvement in a URE. This was expected as past research has theorized that UREs may contribute to students' heightened interest in learning and aspirations for advanced degrees by enhancing their psychosocial competence [6, 10].

Given the findings above, it was then posited that perceived gains in graduate admission knowledge and self-efficacy, made as a result of undergraduate research participation, would explain the relation between minority status and students' gains in graduate degree intentions. Mediation analyses supported the hypotheses, suggesting that self-efficacy and graduate admission knowledge are

important predictors in the association between minority status and computing students' intentions to pursue graduate study. Overall, these findings support the view that REM students' intentions to pursue a graduate degree in computer science may be greatly enhanced by their URE because they are able to develop self-efficacious beliefs and learn about the graduate admission process from participating in a URE.

Although results from this research suggest that psychosocial skills and behaviors that REMs attain through undergraduate research participation are positively associated with gains in graduate degree intentions, this investigation has a number of limitations. First, given the cross-sectional nature of the data, it is not possible to infer a causal relationship among the variables. Future research with longitudinal data is needed to establish causality. Second, there is the possibility that other variables may explain minority status differences in students' heightened intentions to pursue graduate study after having participated in a URE. Future studies should include other predictors of students' educational intentions and outcomes of UREs that were not assessed in this study to test whether the inclusion of these variables improve the explanatory power of the hypothesized models.

These limitations notwithstanding, data resulting from this study indicate that students' perceived gains in self-efficacy and knowledge about the graduate admission process matter, particularly among individuals who are racially or ethnically underrepresented. Although the data used in this research are correlational, the results found point to the need to better understand the role of psychosocial factors in predicting REM students' intentions for graduate study within the undergraduate research environment. Concerning implications, these findings serve as a guide for future research that analyzes interventions that work to improve the educational intentions and career readiness of REM students in computing-related fields.

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