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Research-practitioner Partnerships Supported by the Computer Science for All Program: A Systematic Evaluation

Rahman Adekunle

Mr. John Kofi Eshirow Jr., University of Virginia

John Eshirow is a first-generation fourth-year student at the University of Virginia majoring in Systems Engineering with a concentration in Economic Systems and a minor in Engineering Business. Originally from the Bronx, he grew to have a passion for understanding and developing the intersection of business, engineering, and technology. In the future, John hopes to be an investor and strategic advisor to companies whose mission is to solve a social good.

Mr. Jacob Lam Herring, University of Virginia

Research assistant with the team since Summer 2020

Sin Lin, University of Virginia

Undergraduate Civil Engineering Student at the University of Virginia.

Dr. Rider W. Foley, University of Virginia

Dr. Rider W. Foley is an assistant professor in the science, technology & society program in the Department of Engineering and Society at the University of Virginia. He is the principal investigator at University of Virginia on the '4C Project' on Cultivating Cultures of Ethical STEM education with colleagues from Notre Dame, Xavier University and St. Mary's College. He is the co-PI on the SCC Harlem project funded by the NSF that explores the digital divide and how community-engaged research can address computing needs in New York City. His research focuses on wicked problems that arise at the intersection of society and technology. Rider holds a Ph.D. in Sustainability from Arizona State University, and a Master's degree in Environmental Management from Harvard University and a Bachelor's degree in Environmental Science from University of New Hampshire. Before earning his doctorate, he has worked for a decade in consulting and emergency response for Triumvirate Environmental Inc.

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Abstract

Today, the importance of computer science (CS) education is underscored by the lucrative job opportunities and market growth in the field. Yet every year, many CS-related jobs remain unfilled and further, the demographics of the people filling CS jobs remain highly skewed toward young, White and Asian males. While support for CS education grows across the nation, it is evident that equal opportunity for all students is still not a reality. This prompted the CS for All initiative launched by President Barack Obama in 2016. The initiative aims to empower students from all backgrounds to learn about CS and be equipped with the computational thinking skills needed to excel in the digital economy. One program that was created as part of the President's initiative was the Research-Practitioner Partnership (RPP) grants issued by the National Science Foundation. The program has four objectives: 1) develop a connected community of practice; 2) develop and manage a participant-driven and multi-site research agenda; 3) convene a researcher evaluator working group to develop a process for advancing the shared-research agenda; and 4) collect qualitative and quantitative data about RPP's implementation and common impact data. However, there has been no detailed reports or studies of these funded RPP projects thus making their impacts difficult to observe. Thus, this research entailed a systematic review of the funded RPP programs. The evaluation reveals that the projects are geographically disparate, yet focused on English-language learners in rural communities. The primary mechanism of action (or intervention) is to train educators using train-the-trainer models. Few programs offer tools that extend beyond the one-to-one researcher-practitioner relationships with a couple notable exceptions. This contributes to the lack of training resources that are vetted and supported for educators who aspire to start or augment CS-based curricula. This research suggests that the nascent RPP projects are having positive impacts on a limited number of schools, while the vast majority of schools remain underprepared to administer CS education. The focus on English-language learners suggests that immigrant and refugee populations will continue to remain underserved. This baseline evaluation will serve to support ex post facto assessments in the years to come. Secondarily, research needs to compare city and state-level programs against these national projects funded through the RPP program. There is a need to adapt CS education to be accessible to local school districts and to meet the needs of the demographically and culturally diverse residents and students.

Introduction

Computer science (CS) education offers high-paying job opportunities and has been an area of labor growth for over three decades. Historically, the people recruited into the 'computer' labor pool were overwhelmingly female. The feature film Hidden Figures [1] highlighted the contributions of Mary Jackson, Katherine Johnson and Dorothy Vaughan and the team of human 'computers' that calculated flight trajectories for space exploration. According to the article, *How the Tech Industry Wrote Women Out of History* [2], the characteristics or qualities of 'computers' in the 1950s and through the 1960s, were gendered as female, since the work was understood and advertised to be secretarial. Today, the people trained for CS-related jobs are highly skewed toward young, White and Asian males in the United States and that is associated with a shift in the cultural perceptions and norms. This suggests that for many people in the United States, CS opportunities remain out of reach.

Prior research suggests that the cultural norms about who can work in the computer science field are embedded in education policy and curriculum design. While figures vary between school districts, only 25% of students in kindergarten to 12th grade (K-12) receive computer science education in the United States, according to estimates by the National Science Foundation [3]. President Barack Obama sought to address inequities in CS education by launching the Computer Science for All (CS4ALL) initiative [4]. The program called for over four billion (USD) in the proposed budget for 2014-15. Most of the funds were directed to individual states and municipalities. Those funds encouraged states to build upon the successful efforts of Hawaii, Delaware, Washington and other localities that expanded CS education. An additional $135 million was included in the budget for the NSF and Corporation for National and Community Service (CNCS). This article focuses on the implementation of the CS4ALL program within the NSF. Work by other scholars has surveyed the nation to understand the barriers within different states [5], and cataloged efforts to overcome those barriers within specific localities, for example in New York City [6].

At the NSF, the lead directorate to implement the CS4ALL program was the Computer Information Science and Engineering (CISE) in partnership with other NSF directorates. Four new funding opportunities announced by the White House [4] addressed different needs in research and education. The ITEST (Innovative Technology Experiences for Students and Teachers) and DRK-12 (Discovery Research Pre-K12) were both education and outreach efforts to increase awareness and interest with less emphasis on research. The STEM+C was a program sought to identify the approaches that are best suited to prepare teachers and students in order to engage in CS education. At the nexus of research and education was the CS4ALL: RPP (Computer Science for All: Research-Practitioner Partnerships). This program sought to integrate research teams working on CS education with practitioners trying to educate students [7]. Intuitively, partnering researchers with educators makes sense, yet programs that integrate research and practice are uncommon and can be difficult to assess using traditional research metrics such as number of publications or number of graduate students trained.

Since partnerships between researchers and practitioners are rarely prioritized and infrequently funded by federal organizations, there is a paucity of knowledge about how to assess such programs. This paper aims to explore that important topic by contributing in a small way to that knowledge gap and asking: How are the projects funded by the CS4ALL:RPP program structured and what is the scope and scale of these partnerships? It is important to understand if the funded projects are reaching persons that do not identify as White and Asian males. Specifically, this research assesses the geographic reach, linguistic diversity and rural-urban differentiation. The aim is to critically reflect upon the extent to which the CS4ALL:RPP is reaching children that lack educational opportunities within the field of computer science education.

In the following section, prior work published within the Computers and Education directorate, as well as other pertinent scholarship, is briefly summarized and connections to this research are made clear. The methods of data collection, organization, and analysis are detailed in the next section. The results offer an initial cataloging and review of the projects and programs funded by the Research-Practitioner Partnerships, which is funded by the NSF as part of the CS4ALL program. The discussion focuses on the opportunities for computer science researchers to improve the scale and impact of their partnerships with practitioners.

Literature review

This literature review is far from comprehensive and, as such, is only intended to offer background knowledge and sets the stage for this research project. The literature review first discusses the inequities in CS associated with gender and race within the United States. Then, we detail some of the promising interventions to overcome those inequities, yet those same interventions may be imperfect due to the varying competencies and confidence of educators. This section closes by reviewing the scant evidence on researcher-practitioner partnerships that has been shared by the Computers and Education division at the American Society of Engineering Education.

Gender, race and computer science education

Returning to Brewer's [2] review in *Guardian,* the job of 'computers' was viewed as unskilled work that required only basic mathematics and was further deemed "feminine" with no career advancement opportunities. That shifted in the 1970s when the managerial capacities of computing to control complex systems was recognized and an abrupt change in the demographics followed. "Women were systematically phased out and replaced by men who were paid more and were given better job titles with greater decision-making authority" [2, p. 1].

Today, gender discrimination in CS Education persists, as the OECD [8] detailed in their report, *Bridging the Digital Gender Divide*, which identified barriers to education including the lack of access, affordable education, and simply the absence of CS education in schools. Those barriers are buttressed by inherent biases and sociocultural norms that demean girls' abilities to contribute to technology, in general, and computer science, specifically. These biases contribute to girls' relatively lower educational enrollment in university programs that are classified as science, technology, engineering and mathematics (STEM) disciplines, including information and communication technologies.

Freida McAlear and Allison Scott's [9] article, *Women of Color in Computing*, offers compelling evidence about the intersectionality of gender, race and CS education in the United States. While women of color are a substantial and rapidly growing segment of the total U.S. population, they are alarmingly underrepresented across all areas of technology-related jobs. Many initiatives to enhance diversity among technology-based firms focus on addressing the challenges faced by those marginalized by their racial and/or ethnic or gender identities alone. This ignores the complex and interconnected barriers experienced by women of color, including persons that identify as Black/African-American, Latinx/Hispanic, Native American, Alaskan, Hawaiian, Pacific Islander, or Asian. Without the participation of women and people of color in the creation of new technology, enterprises and solutions will exacerbate trends of wealth inequality and technology-based firms will neglect critical challenges facing diverse communities. McAlear and Scott [10] are launching efforts to intervene in the complex social structures and policies that present barriers to women of color, and we look forward to hearing about the efficacy of those efforts. However, this evidence suggests that significant educational interventions are needed that address the complex intersectionality of gender, race and socio-economic status as it relates to STEM and CS fields.

CS educational programs

Policymakers, scholars and educators alike are calling for changes within K-12 education to address the inequities that fall at the intersection of race, gender, socioeconomic status and STEM education. Those calls are centered around a national commitment to develop a more diverse STEM workforce that offers equitable opportunities regardless of socio-demographic identity. The goals are three-fold. First, generate awareness and interest in STEM among all students at an early age. Second, offer clear educational pathways within every school and through extra-curricular activities, such as clubs and groups. Third, influence a shift in the cultural norms and expectations related to STEM disciplines. One example is the Girl's Day Out program offered in San Diego California and sponsored by the Space and Naval Warfare Systems Center. The Girl's Day Out program was an extracurricular activity that sought to increase the awareness and interest in job opportunities that relied upon CS education. The program offered structured opportunities for staff at the Space and Naval Warfare Systems

Center to interact and mentor girls. The NSF GK-12 program in North Carolina offers an example of curricular reform that offered educators different instructional techniques to align with students' different learning styles and achievement levels. This program offers strategies for educators to incorporate CS education into different grade-levels and with different techniques to generate interest.

Technological pedagogical content knowledge: Key ingredient for CS education

Leanna Archambault and John Barnett [10] revisited the theory that effective learning outcomes depend upon a teacher's ability to align the technology with their pedagogical approach and content knowledge. This is an important consideration for CS education, as teachers must understand how to integrate computer science skills and competencies into their lesson plans. Pilot projects and localized programs have shown success in developing this capacity within teachers. For example, a researcher group from University of Southern California collaborated with nine teachers in three elementary schools in the Latino community of Boyle Heights in Los Angeles and created the Building Opportunities with Teachers in Schools (BOTS) program [11]. The focus of this program is to use robotics and other non-computer-based activities to teach CS concepts in a physical form. One of the long-term goals of the BOTS program is to provide a low-cost and sustainable series of professional development sessions, so the group determined a set of curricula and equipment which would adhere to these constraints. During the sessions, pre- and post-surveys were given and the self-perceived proficiencies of the educators were recorded. Another goal which the researchers have in the future is to make more quantitative measures of the educator's performance and understanding. The BOTS program offers an example for how educators can develop their own ability to teach robotics and create a noticeable improvement in their students' problem-solving and communication skills, which provides a foundation for future CS education. Many other programs, such as the NSF funded project, Transforming Elementary Science Learning Through LEGO Engineering Design [12], offer similar approaches to aligning technology, pedagogy and content knowledge to affect positive learning outcomes. This study effectively integrated engineering design into elementary science education by measuring the students' knowledge before and after instruction through the use of paper tests and semi-structured interviews. The results of the study confirmed pre-existing results from previous research that engineering design can be used effectively to teach science content and that these activities encourage students to practice theoretical scientific principles in everyday contexts and help them establish accurate conceptions of science content.

Researcher-Practitioner partnerships

Sarah Brasiel and Allen Ruby [13] from the Institute of Education Sciences offered four clear objectives for researcher-practitioner partnerships:

- What works to improve student educational outcomes, so that we can disseminate it?
- What does not work, so we can stop using it?
- What works for whom and where, so we can use it with the appropriate people in the appropriate places?
- Why does it work, so we understand how to improve education and can build on this understanding?

The presentation by Brasiel and Ruby offers important assessment questions for the evaluation and continuous improvement of researcher-practitioner partnerships. She argues that there is a misalignment in the goals for the two parties engaged in the partnership. Drawing upon a case study, Brasiel and Ruby [13] showed how relationship building and mutual goals enabled the success of both parties. Frequent communication and shared success and achievements that benefitted all parties supported the collaborative efforts of the team members, which ultimately contributed to positive research and student outcomes.

The principles that Brasiel and Ruby [13] pointed to were further elucidated by Jennifer Turns and colleagues [14], whose work focused on the challenges associated with translation of educational research into educational practice. The field of education is not alone in this struggle and many scholars have detailed the challenges of translating abstract knowledge into practice-oriented (or use-inspired) knowledge [15]. Projects need to be designed in a manner that allows educators or other project-partners to make direct use of the lessons learned from the research-side of the project. Otherwise, the researchers may very well describe and analyze the failings of the educator or educational system, but in no way contribute to the transformation or improvement of the educational practice. Thus, as Turns and colleagues suggested, research partners should take into account the prior knowledge and interpretive frameworks that the practitioners' start with and the trajectories associated with learning in a particular domain [14]. Researchers should assess the practitioners' learning needs and assist in the development of more effective learning experiences. Drawing upon a review of 273 articles, Turns and colleagues argued that research should be designed to influence policymakers and to offer guidance to funding agencies about setting priorities and evaluating programs, and provide educators with empirical evidence about techniques that can improve student outcomes [14]. Together, these people can function as change agents helping to advance the effectiveness of engineering design education.

Research design

The research question addressed by this project is: How are the projects funded by the CS4ALL:RPP program structured and what is the scope and scale of these partnerships? To address this question and contribute, in a small way, to the assessment and evaluation of researcher-practitioner partnerships, this research draws upon evidence from the NSF CSforALL

RPP programs between 2017 and 2019. Thirty-seven projects funded by that program were cataloged and project-level data were downloaded from publicly accessible websites hosted by the NSF, universities, nonprofits and other educational organizations. That data was organized systematically into a table that contained the following information about each project (see Supplement Materials for full table):

1. Principal Investigators Names
2. Project Websites, and in the case of those without websites, the NSF award was used
3. Educational or community organization affiliated with the project
4. Statement of work or goal that guided the project
5. Target audience for each project
6. Projects that explicitly targeted non-English language learners were noted
7. Target location where each project was implemented
8. Type of partnerships each project, which were categorized as either academic partnerships, non-profit, government institutions, or direct work with schools
9. Each project was classified as a start-up program, a program that seeks to enhance on other previous programs, or a research study with goals is to measure the effects of specific interventions
10. NSF award amount for each project

Secondarily, the data were assigned a numerical code that allowed for some direct graphical representation of the qualitative data gleaned from the public sources. For example, projects were assigned 0 = English and 1 for non-English Language, which allow the research team to analyze the data from the table quantitatively. Given the sample size (n=37), no correlations, regressions or other statistical approaches were taken to analyze this data. Any such attempts would be deeply flawed, cf. Mertens [16]. Thus, descriptive graphics and charts were used to identify patterns and commonalities. Geographic mapping of the projects to the associated localities was conducted with Geographical Information System (GIS) software and the proportion of funding projects was mapped as well. This exploratory research project offers its findings as points of reflection for the public funding organization, and to the researchers and practitioners in the field. The research design and our exploratory dataset, while systematic, are not robust enough to make causal claims.

Findings

The projects supported by the NSF's CS4ALL program that focuses on Research-Practitioner Partnerships are distributed in ways that privilege English-language speakers, and augments existing programs in rural areas. The funding supports English-language focused computer science programs with far less support for non-English language programs. Further, this initial assessment shows that the largest grant recipients are given to existing programs that are being enhanced with the research funds. Thus, this suggests a pattern whereby pre-existing disparities between different social groups are potentially being reinforced. The results serve to support two main claims with descriptive statistics from the systematic review of the funded projects, see Table 1 below, and underpin the interpretations. Predominantly, the mode of action for the researcher-practitioner partnerships centers on a train-the-trainer model and seeks to augment existing programs. This approach promises a broader reach than targeted research within one classroom, school or even school districts. The projects often seek to integrate lessons that teach computer science skills and competencies into existing curriculum in a manner that aligns with Standards of Learning. The two primary target populations are traditionally underserved communities in rural regions where internet infrastructure is lagging and educators are creating and/or seeking to expand computer science programs for K12 students. The implications of these findings are discussed in the closing section.

Table 1. Synthesis of projects funded by the NSF's CS4ALL RPP program between 2017 and 2019. Notes: Project Form was classified into Start-up, Enhancement of Existing Programs, or Measurement. Note: Geography was classified as urban or rural based upon the geographic reach of the program. State-wide projects were coded as both urban and rural.

Project Name (Shortened)	Target Audience	Project Form	Geography	Award Amount	Non-English?
Growing Teacher CC	CS Educators in K-8	Start up	Urban and Rural	$770,757.00	No
Collaborative Network of Educators	Underserved students in G3-5	Start up & Measuring Effects	Urban	$315,556.00	Yes
Understanding Equity in a CSforALL Implementation	African American, Hispanic, and socio-economic status	Enhancement	Urban	$999,891.00	No
A Scalable RPP for Preparing Teachers	Educators/ Teachers	Enhancement	Urban	$1,130,316.00	No
Development of CS Principles Courses	Teachers in 8th to 12th	Enhancement	Urban	$1,000,000.00	No
Broadening Pathways into Computing	Elementary School Teachers	Start up	Urban	$998,737.00	No
Developing Board Games	5th Grade Students	Start up	Urban	$323,999.00	No
Developing Inclusive K–12 Computing	K-12 Students	Start up	Urban	$1,191,260.00	No
Expanding Pathways into CS	Underserved Students in South Dakota	Enhancement	Rural	$784,917.00	No

Develop a Shared Evaluation and Research Agenda	Researchers and Practitioners	Start up	Urban and Rural	$1,414,165.00	No
ECS4PR	Spanish-speaking communities in Puerto Rico	Enhancement	Urban	$300,000	Yes
Educational RPPs as Education Policy	N/A	Measuring Effect	Urban	N/A	N/A
CS4GA	K-12 students, underrepresented in Georgia	Start-up	Urban and Rural	$50,000	No
INTech Camp	High school girls	Start-up	Urban	N/A	No
Integrate to Innovate	Rural youth in Maine	Enhancement	Rural	$300,000	No
Integrating CS and Computational Thinking	Rural youth in North Carolina	Enhancement	Rural	$1,000,000	No
Next Door to Silicon Valley: Access Disparities	Grades 3-8 in underserved communities	Start-up & Measuring Effects	Urban	$300,000	Yes
Pairing High School Teachers with HBCU CS Students	Minority high school students in Atlanta	Start-up	Urban	$316,000	No
Computational Thinking	Educators teaching G3-8.	Start-up	Urban	$996,361.00	No
Integrate CS in SoLs	Educators teaching grade k-5.	Start-up	Urban	$999,423.00	No
REAL-CS	High School Teachers, students, and parents.	Enhancement	Urban and Rural	$2,100,000.00	No
ScratchEncore	Upper Elementary School teachers	Measuring Effects	Urban	$1,262,256.00	No
SCALE-CA	California students	Measuring Effects	Urban	$2,000,000.00	No
Statewide Network	CS Teachers in Northern Iowa	Start-up	Urban and Rural	$299,984.00	No

ECEP	K-12 and beyond	Enhancement	Urban and Rural	$2,766,363.00	No
Uteach and NYC	Teachers and public school administrators	Enhancement	Urban	$999,953.00	No
Cyber security pathway	High school in a majority-Latino district.	Enhancement & Measuring Effects	Rural	$999,737.00	Yes
AWSM in CS	K-12 women	Enhancement & Measuring Effects	Urban and Rural	$1,180,281.00	
K-8 CS Education	K-8 Educators working with Native Americans	Enhancement & Measuring Effects	Rural	2,000,000	No
Broadening CS Participation	K-12 Students	Enhancement	Urban	$999,865.00	No
AccessCSforAll	K-12, focus on deaf, blind, and learning disabled	Enhancement	Urban	504,458.00	No
Building a Pathway for CS Principles	Pre-service educators	Startup & enhancement	Rural	299,903.00	No
Scalable Model to Broaden Participation in CS	African American, Latinx students in 6th to 8th grade	Enhancement	Urban	502,822.00	No
Broadening Participation of Teachers and Students	K-12+	Start-up	Urban and Rural	$657,511.00	No
Preparing Teachers for CS Instruction	High School teachers	Enhancement	Urban	610,000.00	No
Identifying Participation Barriers to CS Education	K-12+ in Rural Mississippi	Start up and Enhancement	Rural	$266,496	No
Computer Science for Oregon	High school, underrepresented groups in Oregon	Enhancement	Urban and Rural	999,945.00	No

Diversity of languages

There are many programming languages in which computer code can be written, whether it be in Python, Java, or for the more technically proficient, C++. These languages are all largely derived from the English language, yet can be mastered by people with no English-language proficiency. In many respects, learning to code is about learning how to cognitively structure tasks in a manner that can be communicated to a computer. Yet, our assessment of the projects funded focused on the computer coding language, and not on the spoken and written language associated with the educational program. Of all the programs funded by the CS4ALL initiative, only 4 specifically targeted non-English speakers, while 34 served English speakers. Further, the projects that accommodate non-English speakers, on average, received less funding than those that just serviced English speakers: $904,027.31 (English language) versus $478,823.25 (non-English language). Looking further into the non-English language programs, those projects targeted Spanish speaking communities. This does not reflect the diversity of languages spoken in homes in the United States, nor does it reflect the breadth of non-English languages accommodated by many school districts across the country. There is a need to expand the reach of these programs that teach coding so that students living in non-English speaking households can benefit from receiving a computer science education, which is becoming more of a ‘norm’ in the school and workforce. Without a workforce consisting of people from diverse backgrounds that reflect our country’s population, there will subsequently be a lack of this same diversity in the generations that may be interested in learning the computer coding language. This will perpetuate aspects of implicit bias that affect hiring decisions, and constrain the growth and potential of the computer science field. This an important topic for discussion, which we return to later, in an analysis of the cultural-linguistic perspective of this issue.

Project focus: Start-up versus enhancements

The RPP project currently depicts a pattern where the enhancement of existing programs garnered almost three times the funding as start-up programs. Evaluation alone was the least funded project type, see Figure 1 below. Though quite a few projects combined aspects of enhancement and evaluation or start up and evaluation, see Table 1 above. The projects funded show a clear pattern of selection bias for enhancing existing programs that deliver CS education and that selection bias might come at the cost of creating new start up projects in community where there are no CS educational opportunities. This speaks to the geographic diversity of the projects funded and suggests that rural communities with existing programs might very well be benefitting disproportionally from RPP, while urban regions that lack sufficient programming are falling further behind. This suggests a potential future research question that may further shed light on the inequality in funding across regions in the United States by analyzing the value of a dollar in different regions, say, urban areas compared to rural areas. Thus, it may be necessary to take into account the cost of living, CS education and programs, as well as the current funding for educators and infrastructure across regions as we analyze the reach of CS education programs. Ideally, it would be possible to balance the costs of running a program in any region, urban or rural, to best serve its respective demographic.

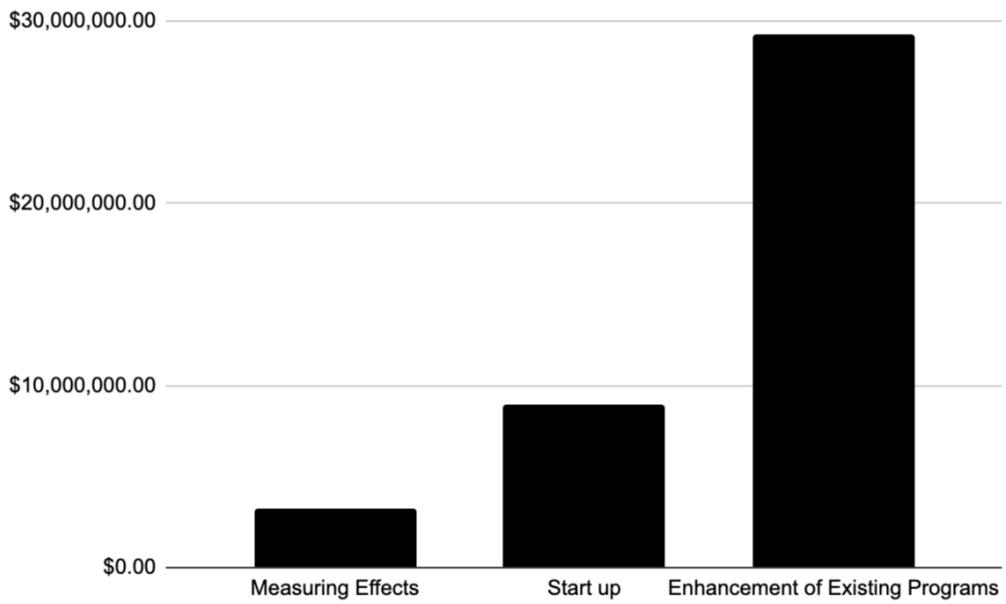

Figure 1. Funding allocations across program type.

Geographic diversity

At first, the assessment showed a disproportionate number of projects were located in urban areas and connected to specific school districts and city administrations, see Figure 2. There were only seven projects that focused on rural school districts, while 21 projects were connected to urban school districts. The projects grouped as both urban and rural were all state-wide initiatives where the project outcomes affected both large cities and rural regions. Taken at face value, this depicts a higher concentration of projects located in urban areas where internet connectivity is generally more accessible. The financial geography shows that these projects target major US cities with concentrations in the Northeast and Mid-Atlantic, as well large projects in Texas, Southern California and Pacific Northwest cities, see Figure 3. The scope and scale of this program at NSF suggests that vast regions of this nation are not being served and this level of funding is insufficient in facilitating nationwide change. The geographic distribution appears to be weighted towards urban programs in major cities, but that is not an accurate representation. Yet, Figure 4 shows that the small number of rural projects received more funding than the urban-focused projects. Thus, areas of low population density were allocated greater sums of funding. This means that rural areas received comparatively more funding than urban projects based upon their population density .

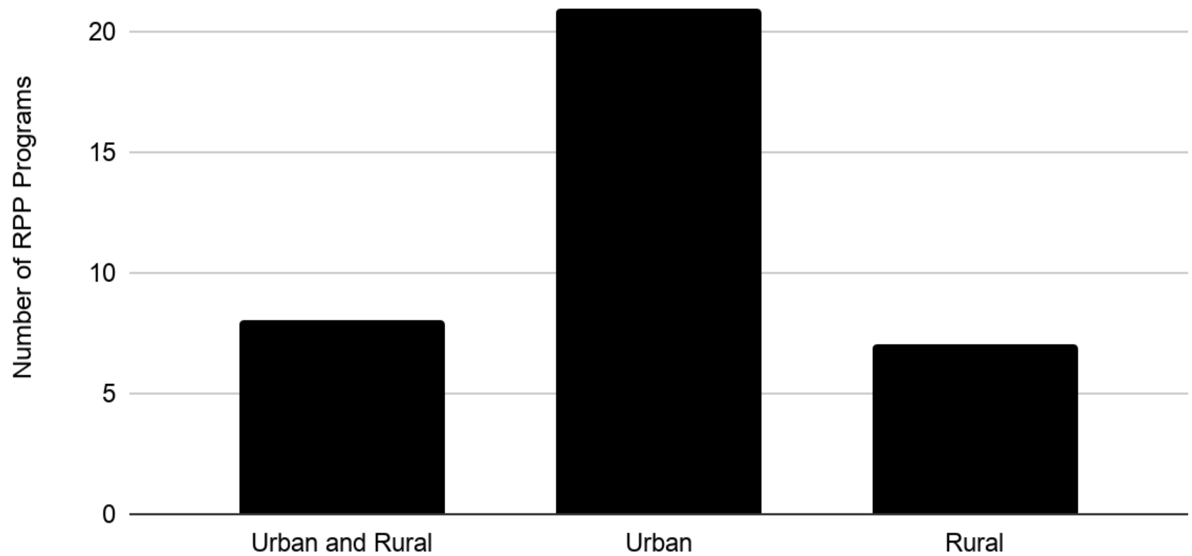

Figure 2. Geography of projects funded as classified by urban, rural and state-wide projects that impact both urban and rural regions.

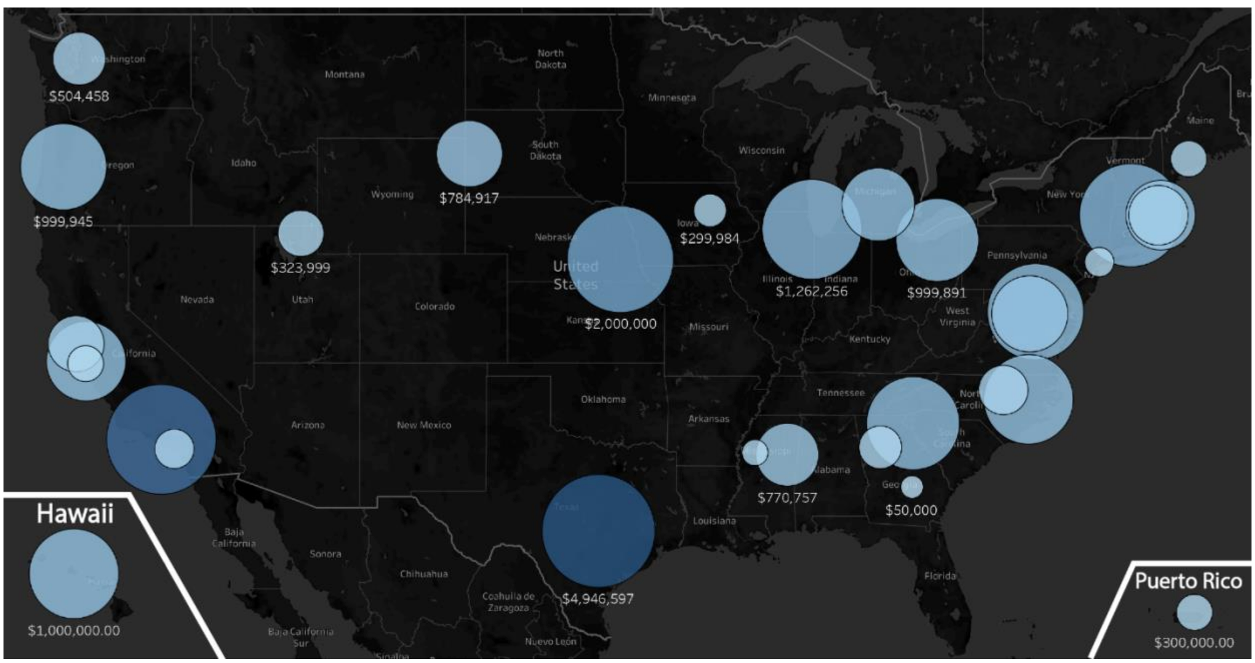

Figure 3. Financial Geography. Locations of projects are geolocated, while the circle size is proportional to the amount of funding.

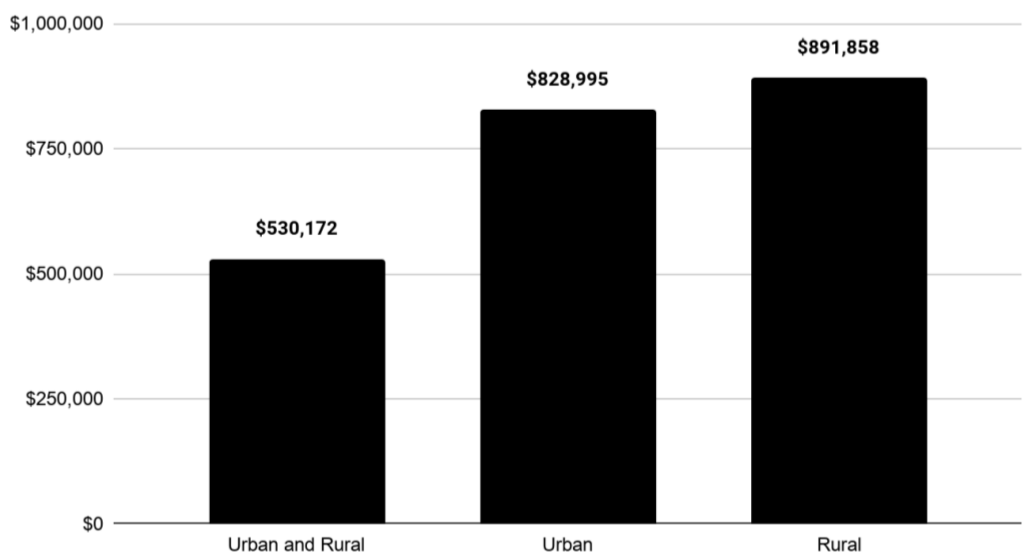

Figure 4. Mean project funding by geographic region.

To explore this issue further, though it is not directly related to this assessment, our research team mapped the extracurricular CS Education opportunities in New York City, see Figure 5, to show how geographic disparities can exist even within the bounds of a single city. With nearly one million K-12 students in the NYC public school system, one would hope that each could have equal opportunity and access to a CS education. However, as can also be seen nationwide, these opportunities are overwhelmingly concentrated within the most affluent school districts. What's more, those more affluent areas of NYC such as Lower and Midtown Manhattan, which do have access to CS education, are largely skewed with regards to racial/ethnic demographics. The areas containing the deepest shade of blue in Figure 5 (known as Lower Manhattan and Downtown Brooklyn) correspond directly with areas containing predominantly White/Caucasian residents, thus again highlighting the socioeconomic factors which dictate what social groups have access to CS educational opportunities.

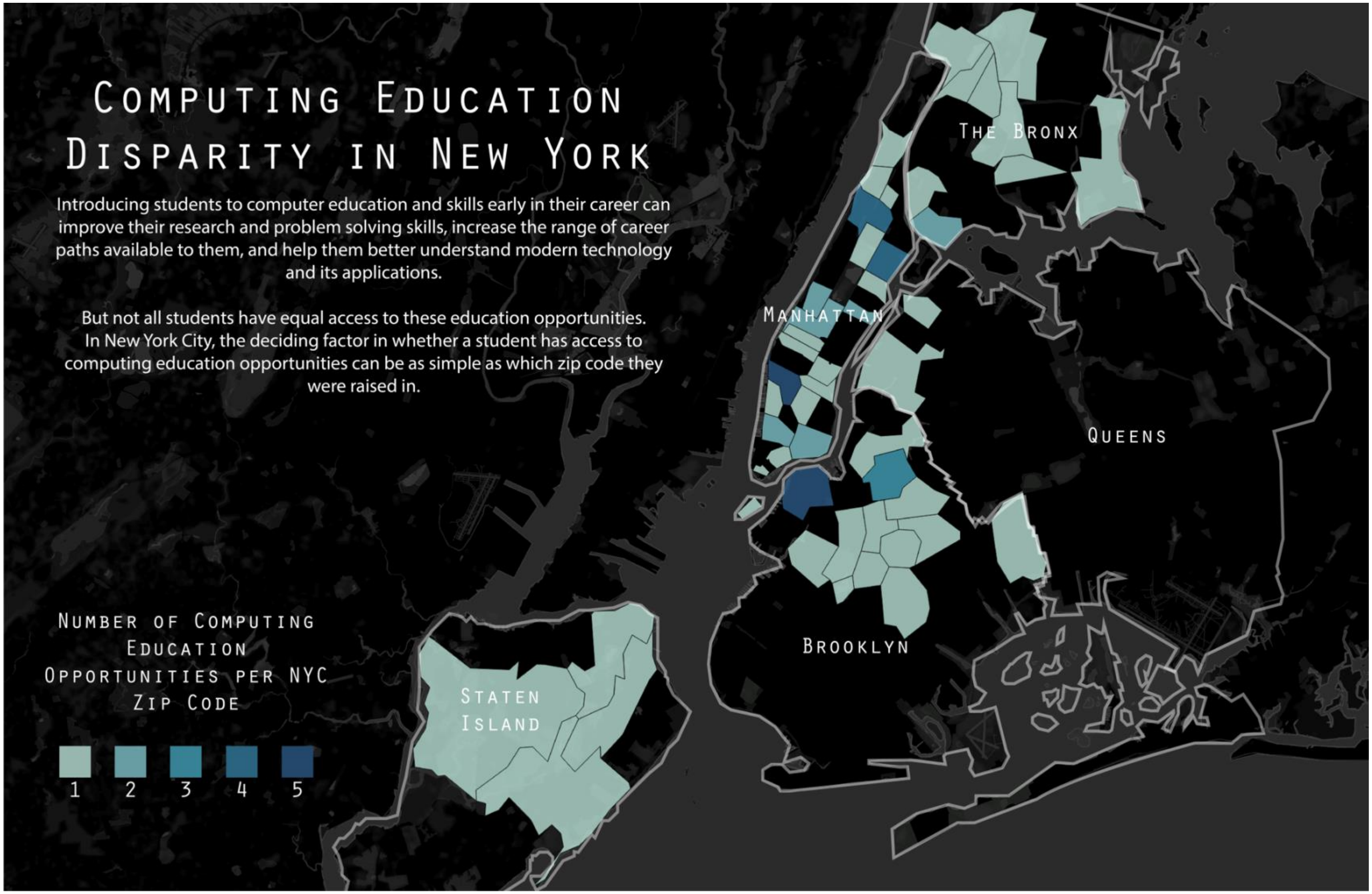

Figure 5. CS education opportunities in New York City. Note: The research team cataloged and created the graphic.

Discussion

The intention of this research was not to assess the value of CS education or to evaluate the specific techniques or approaches taken by individual projects. Rather, the intention was to step back and look at a nation-wide program funded by NSF to deliver on the Computer Science for All initiative that was launched during the Obama Administration. At first glance there is good balance between urban and rural programs and geographic diversity from east to west and north to south. Yet patterns are emerging, which suggest that existing programs in rural areas are benefitting disproportionally to urban areas. Those existing programs might well serve as models for other cities and states, yet that would require extensive communication and outreach between civic leaders and educators. The detailed look at New York City suggests that there are huge populations in major US cities living in less affluent urban communities that lack access to CS education. So, despite the breadth of the projects funded, it is unclear if these projects and this level of funding are going to have measurable impacts. For many of the RPP projects it is too soon to evaluate the specific impacts and outcomes. What the results suggest is that the focus on English-language educational programs will force students to learn English first and then learn CS, rather than learning CS and English in parallel or even learning English via CS programming and language courses.

Towards a theory of CS education: A cultural-linguistic perspective

A finding that stands out is the apparent focus on English-language learning that underpins a vast majority of the computer science projects funded by this program. Of the 36 projects analyzed above, the NSF funded only 4 (11%) projects that accommodate non-native English speakers. This is less than the 38% of children speaking a language other than English at home. This reflects that computer science is a lower priority than English-language proficiency. Thus, students need to learn the English-language before learning computer science. Yet, that prioritization ignores the implicit bias in that ordering and, secondarily, ignores decades of educational research on CS education. To the first point, if students need to learn English first, then immigrants and refugees and children raised in non-English speaking households are at distinct disadvantage. A recent report from data gathered between 2010 and 2019 suggests that at least 11 million children between five and seventeen speak a language other than English in their homes [17]. That is approximately 22% of all children within that age range in the US. This is even more important in major US cities, where 38% of children speak a language other than English at home [18]. Coupled with language are many cultural attributes, for example different values, cognitive representations of the world, and approaches to problem-solving. So, by requiring students to learn English first, before learning CS, the educational system is implicitly structured to discriminate against children raised in non-English speaking households. This raises a question, does English need to be taught before students engage with CS education? This question brings us to our second point.

For over forty years, scholars and computer scientists, such as Moyne, articulated the clear relationships between linguistics and computer coding [18]. A decade later, Underwood [20] published Linguistics, Computers, and the Language Teacher: A Communicated Approach that served as a foundation for many studies on the relationships between teaching linguistics and how to bring computers into that approach. Interestingly, many educational researchers and CS professionals use computers to teach students foreign languages, for example Chapelle [21], but there is far less published on teaching English as a Second Language (ESL) students to code. However, fewer scholars considered how learning the computer coding language might well support synergist outcomes in English-language learning [22]. This creates new possibilities for students that are not proficient in English, and thus implicitly excluded from CS education. For if learning to code is essentially learning a language, then can those lessons be taught simultaneously or in parallel to English-language proficiency? Current efforts of the majority of coding programs assume English proficiency, which, again, puts non-English speakers at a disadvantage and may be greatly discouraging for those who may wish to further pursue a computer science education. Yogendra Pal [23], dissertation, "A Framework for Scaffolding to Teach Vernacular Medium Learners," sheds some light on how vernacular medium learners - students who studied in their primary language from grades K12 and move on to do their undergraduate education in English - best acquire programming knowledge. Pal suggests that a self-paced video-based environment taught in the students' primary language is more effective than a classroom environment if English-only medium of instruction are used. This is because students are more able to cognitively organize the information being taught if they can pause and rewind the videos in order to understand new vocabulary or concepts. While the CS education in a English-only classroom setting can overwhelm or discourage non-English speaking students from asking questions.

There are obvious challenges in teaching non-English speakers the English language and a programming language in parallel, since programming languages utilize specialized English vocabulary and syntax rules that are harder to grasp and thus take a lot of time to effectively teach. Not to mention, the obvious challenge of the limited access these students may have to computers and the Internet at home, as well as the challenge of the lack of infrastructure and trained instructors that can serve non-English speaking students effectively. However, introducing CS to ESL students early on in their education may be beneficial in exposing them to the concept of computer science and computational thinking before or as they learn more in-depth English. To reach the 22% of US children that do not speak English at home, the National Science Foundation should fund projects that build synergies between English as a Second Language (ESL) and CS Education. Such a project could foster partnerships between CS educators and ESL educators and researchers to create, disseminate and evaluate modules for teaching CS. A pilot project might very well offer lessons to children that speak Spanish, Chinese, Arabic and Vietnamese, which are the four most common languages after English in the US [24]. The modules could couple CS and ESL learning outcomes and be disseminated widely to urban school districts to have more far-reaching impacts. Such a project would break out of the geographic-oriented approach currently taken and positively affect millions of children.

Limitations

This study does not offer statistically significant data, nor does it offer a detailed review of specific projects and their outcomes. The aims here were more modest and that means that our findings are limited by the research design. Only one programmatic area of NSF funding was reviewed and thus, the geographic extent and diversity of CS education and research project is, of course, far broader. Stepping back from the NSF, this study does not delve into the efforts by the US Department of Education to coordinate CS education, nor do we review the state-based programs that were funded by the CS4ALL initiative launched by the Obama Administration. The majority of all funding was directed to those state-based initiatives and those programs have been evaluated by other scholars. For example, Lim and Lewis [25], offered metrics for success and how those align with demographic patterns in CS education. Not surprisingly, when looking at advanced placement tests for CS, persons that identify as Black, Hispanic, Native American, and Pacific Islander were all under represented. That finding is quite common and suggests that systemic issues associated with race and ethnicity associated with CS education. Work remains to identify successful models of CS education connect to persons from non-English and non-White households. The evaluative questions offered by Brasiel and Ruby [13] are not addressed, as the projects have neither been completed, nor have they publicly reported on the research outcomes. Future research should evaluate what worked and had measurable effects on student educational outcomes and what did not work and how the context informed the results.

Conclusion

The primary goal of these programs from the onset was to make early computing education accessible to kids all across the nation in order to promote further CS learning throughout student's educational careers. The expectation for many of these RPP programs was that they could potentially serve as first contact initiatives for kids in rural and urban areas where quality CS education is less accessible from a younger age, but that did not seem to be the case after further analysis of these RPP programs as the demographics mostly in need of these programs such as students from underserved backgrounds and English language learners were not receiving the benefits of these programs to the fullest extent. This could be a result of many things; from funding to lack of attention by administrators in charge and much more. If we can't get this right, the disparities and inequities in early CS access will continue to translate and further the gaps present in the CS workforce.

The investment made by the CS4ALL initiative brought additional resources to states across the nation that allowed for the initiation of projects that brought researchers and practitioners together to tackle the digital divide. This initial assessment of the NSF-funded RPP may give policymakers pause; the RPP funding has been skewed towards enhancing existing programs and there is an imbalance between urban and rural schools, not to mention the obvious lack of language diversity. Considering these points of observation, this suggests that English-speaking students in rural areas that already have computer science education and programs are benefitting from the NSF-funded RPP. This assessment does not offer metrics for success, but rather highlights the emergent patterns after the first few years of funding. The implicit bias that excluded ESL students signals yet another potential cause for the lack of diversity in students that take the Advanced Placement tests in Computer Science and reflects the lack of diversity in the CS workforce. Identifying the neighborhoods and communities within dense urban areas where CS educational opportunities are lacking, as shown for New York City, reveals that the digital divide is not just a rural problem, but that it impacts our cities as well. Funding decisions need not only showcase the best approaches, but also address the legacy injustices and inequities that plague our nation.

References

[1] T. Melfi, *Hidden Figures*. 20th Century Fox, 2017.

[2] K. Brewer, "How the Tech Industry Wrote Women Out of History." The Guardian, August 10, 2017. Available at: https://www.theguardian.com/careers/2017/aug/10/how-the-tech-industry-wrote-women-out-of-history

[3] White House, "FACT SHEET: A Year of Action Supporting Computer Science for All." 2016. Available at: https://obamawhitehouse.archives.gov/the-press-office/2016/12/05/fact-sheet-year-action-supporting-computer-science-all

[4] White House "President Barack Obama sought to address inequities in CS education by launching the Computer Science for All (CS4ALL) initiative." 2016. Available at: https://obamawhitehouse.archives.gov/blog/2016/01/30/computer-science-all

[5] J. Wang, H. Hong, J. Ravitz, S.H. Moghadam, "Landscape of K-12 Computer Science Education in the U.S.: Perceptions, Access, and Barriers," 47th ACM Technical Symposium, February, 2016.

[6] C. Fancsali, L. Tigani, P.T. Isaza, and R. Cole, *A Landscape Study of Computer Science Education in NYC: Early Findings and Implications for Policy and Practice*, 49th ACM Technical Symposium. February, 2018. DOI.10.1145/3159450.3159467

[7] NSF. "Call for Proposals: Computer Science for All (CSforAll: Research and RPPs)," 2020. Available at: https://nsf.gov/funding/pgm_summ.jsp?pims_id=505359

[8] OECD. "Bridging the Digital Gender Divide." 2017. Available at: www.oecd.org/digital/bridging-the-digital-gender-divide.pdf

[9] F. McAlear. Scott, *Women of Color in Computing: A Researcher-Practitioner Collaborative,* Annual Meeting of the American Society of Engineering Education, April 14 2018. Available at: https://peer.asee.org/women-of-color-in-computing-a-researcher-practitioner-collaborative

[10] L.M. Archambault, and J.H. Barnett, "Revisiting technological pedagogical content knowledge: Exploring the TPACK framework," *Computers & Education,* vol. 55, no. 4, pp. 1656-1662, 2010.

[11] J.L. Cough, P. Chaffey, G. Salhotra, C.G. Cess, R. Pocius, and K. Mills, "Building Early Elementary Teacher Confidence in Teaching Computer Science Through a Low-Cost, Scalable Research-Practitioner Collaboration," American Society of Engineering Education, June 22-26, 2020.

[12] I. Marulcu, and M. Barnett, "Fifth Graders' Learning About Simple Machines Through Engineering Design-Based Instruction Using LEGO™ Materials," *Research in Science Education*, vol. 43, pp. 1825-1850, 2013.

[13] S. Brasiel, and A. Ruby, *Researcher-practitioner Partnership in Education Research*, Washington DC: Institute of Education Sciences National Center for Education Research, 2018

[14] J. Turns, M. Cardella, C. J. Atman, J. Martin, and J. Newman, "Tackling the Research-to-teaching Challenge in Engineering Design Education: Making the Invisible Visible," *International Journal of Engineering Education* , vol. 22, pp. 598-608, 2006.

[15] D. Sarewitz, R. Pielke Jr., and L. Dilling, "Creating Usable Science: Opportunities and Constraints for Climate Knowledge Use and Their Implications for Science Policy." Consortium of Science Policy and Outcomes, 2010.

[16] D. Mertens, *Research and Evaluation in Education and Psychology: Integrating Diversity with Quantitative, Qualitative, and Mixed Methods*. Thousand Oaks, CA: Sage Publications, 2006.

[17] The Annie E. Casey Foundation, "Children Who Speak a Language other than English at Home in the United States," 2020. Available at: https://datacenter.kidscount.org/data/tables/81-children-who-speak-a-language-other-than-english-at-home#detailed/1/any/false/1729,37,871,870,573,869,36,868,867,133/any/396,397

[18] US Census, "Census Bureau Reports at Least 350 Languages Spoken in U.S. Homes," 2015. Available at: https://www.census.gov/newsroom/press-releases/2015/cb15-185.html

[19] J.A. Moyne, "Relevance of computer science to linguistics and vice versa," *Journal of Computer & Information Sciences*, vol. 4, pp. 265-279, 1975.

[20] J. Underwood *Linguistics, Computers, and the Language Teacher: A Communicated Approach.* Cambridge University Press, Rowley, MA. 1984.

[21] S. Chapelle, *Computer Applications in Second Language Acquisition: Foundations for teaching, testing and research.* Cambridge University Press, Rowley, MA. 2001.

[22] G. R. Skuse, and D. A. Walzer, “Computer Science and the Liberal Arts: Hidden Synergies and Boundless Opportunities,” In *New Directions for Computing Education*, S.B. Fee, A.M. Holland-Minkley, T. Lombardi, Eds. Zurich: Springer, 2017

[23] Y. Pal "A Framework for Scaffolding to Teach Vernacular Medium Learners," Indian Institute of Technology – Bombay. Doctoral Dissertation, 2016

[24] C. Mitchell “The Five Most Common Native Languages of English-Learners,” Education Weekly, October 12, 2018. Available at https://www.edweek.org/teaching-learning/the-five-most-common-native-languages-of-english-learners/2018/10#:~:text=Spanish%2C%20Arabic%2C%20Chinese%2C%20Vietnamese,the%20U.S.%20Department%20of%20Education.

[25] K. Lim, and C. M. Lewis, “Three Metrics of Success for High School CSforAll Initiatives: Demographic Patterns from 2003 to 2019 on Advanced Placement Computer Science Exams,” Proceedings of the 51st ACM Technical Symposium on Computer Science Education, February, 598–604, 2020.