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COMMENTARY

Building Educational Capacity for Inclusive Geocomputation: A Research-Practice Partnership in Southern California

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ABSTRACT
To build educational capacity for the rapidly evolving science and profession of geocomputation, the American Association of Geographers piloted an Encoding Geography research-practice partnership (RPP) composed of geography and computer science educators and researchers. This commentary describes the process, known as Collective Impact, that was implemented to investigate the persistent problems of practice that have limited the participation of women and minorities in geocomputational education and careers. We also discuss the RPP's data-driven approach for developing an inclusive curriculum pathway aligned with student aspirations.

KEYWORDS
Computer science; Careers; Powerful knowledge; broadening participation; geography

Introduction

Geospatial technologies including Geographic Information Systems (GIS) and the Global Positioning System (GPS) are now used across a wide array of Science, Technology, Engineering, and Mathematics (STEM) disciplines and career areas (Dony et al. 2019a). In recent years, the consumer appetite for geospatial services created approximately four million direct jobs and generated 400 billion U.S. dollars globally in annual revenue (AlphaBeta 2017).

The continuing growth of the geospatial technology industry is increasing the demand for high school and college graduates with proficiency in both geography and computer science (which we will refer to hereafter as "geocomputation"). Yet despite this demand, the nation presently suffers from a limited capacity to offer curriculum and learning pathways that combine training in both disciplines (Dony et al. 2019 b, Magdy and Dony 2020). This has created a scenario in which employers across the public and private sectors have to choose between hiring a geographer with limited or no computational skills, or a computer science or engineering graduate with limited or no expertise in geography. According to one recent industry study, 80 percent of employers believe that it is "difficult" or "very difficult" to hire data scientists with expertise in spatial analysis (Broderick and Álvarez 2020).

At the K-12 levels, schools are slowly beginning to leverage geospatial technologies to support computational thinking in the social studies. History teachers are attracted to hands-on uses of geospatial technology for learning spatial concepts and skills of data collection, analysis, and communication with geo-visualizations (Hammond 2014). Meanwhile, at the college level, computer science departments are starting to offer courses that involve the use of spatial data. These courses, however, often lack basic yet key disciplinary content knowledge from geography to accompany students' training with GIS and other analytical mapping technologies. At risk here is the potential of misused or mishandled spatial information, misinterpretation of spatial analyses, and misinformed decision-making (Couclelis 2003). And while academic geography departments are starting to offer courses that involve some computational thinking, only a handful of departments have the capacity to offer a degree or certificate that integrates knowledge and skills in geography and computer science (Bowlick, Goldberg, and Bednarz 2017).

Adding to the challenge of meeting workforce needs related to geocomputation is the persistent underrepresentation of women and minorities in geography and computer science. In a recent study from Wang et al. (2019, p. 8) involving analysis of close to three million papers, they suggest that, "based on recent trends, the proportion of female authors in computer science is forecast to not reach parity in this century." In geography, this underrepresentation is also visible. According to disciplinary data available from the AAG (Keen 2018a, 2018b), among the 2016-17 recipients of a bachelor's degree in geography 37.8 percent were women (compared to 57.3 percent among recipients in all

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higher education). White, non-Hispanic students accounted for 75 percent of all geography undergraduate students in 2016, while the proportion of white, non-Hispanic undergraduates in all degree fields was only 55 percent. African Americans comprised 14 percent of all undergraduate students in 2016, but only 3.7 percent of geography students. Hispanic/Latino and Asian students were also significantly underrepresented in undergraduate geography programs relative to other majors.

Studies have shown the far-reaching consequences of the underrepresentation of these groups in terms of innovation, bias, and workplace culture. In 2015, Mazur and Albrecht published the first substantial piece of empirical research on women in the GIS profession. In surveying almost 500 women in GIS, the authors conclude that although women are not as grossly underrepresented as in the overall technology industry, they are likely underrepresented in certain sectors and positions. For example, the authors found women are underrepresented in the private sector of the GIS industry and in positions that require managerial or advanced programming skills (Mazur and Albrecht 2015).

Piloting a research-practice partnership for inclusive geocomputation

With funding support from the National Science Foundation's Computer Science for All (CSforALL) program,[1] the American Association of Geographers (AAG) established the Encoding Geography research-practice partnership (RPP) in a pilot study based in Southern California. RPPs are "long-term, mutualistic collaborations between practitioners and researchers that are intentionally organized to investigate problems of practice and solutions for improving district outcomes" (Coburn, Penuel, and Geil 2013). Individuals comprising the Encoding Geography RPP are geography and computer science educators and researchers. Institutions represented in the RPP include the Sweetwater Union High School District (SUHSD), San Diego Mesa College (SDMC), the University of California-Riverside (UCR), San Diego State University (SDSU), and the California Geographic Alliance (CGA). Texas State University is also represented in the RPP to coordinate the partnership's activities via the National Center for Research in Geography Education.

The goal of the Encoding Geography RPP pilot study was to investigate and propose solutions to persistent problems of practice that have limited capacity in many educational organizations to increase the participation of women and minorities in geocomputation. To guide this work, the RPP implemented a working process known as Collective Impact (Kania and Kramer 2011). Collective Impact is a framework for successful, equitable, and enduring collaboration for social change, based on five conditions:

1. the development of a ***Common Agenda*** which documents the common understanding of the problem and the associated challenges of attaining a shared vision for change;
2. the agreement on ***Shared Measurement*** allowing tracking and comparative analysis of partners' achievement of objectives;
3. integrating ***Mutually Reinforcing Activities*** that complement and find synergy in efforts by network members at all levels;
4. upholding ***Continuous Communications*** to coordinate the work of partners and share resources, materials, and tools among network members;
5. a ***Backbone Organization*** with a dedicated staff and a specific set of skills to support the entire initiative and coordinate participating organizations and individuals. As co-headquarters of the National Center for Research in Geography Education, the AAG and Texas State University collaboratively serve as the backbone organization for the Encoding Geography RPP.

The Encoding Geography RPP's Common Agenda was collaboratively developed by its members through a series of workshops, both in-person and virtual, over a period of 18 months. The Common Agenda identifies the persistent problems of practice in computer science and geography at different levels of education, namely (i) the lack of awareness about careers (because both geography and computer science have such broad possibilities), (ii) difficulties with broadening participation, and (iii) large (and growing) gap between knowledge and skills students graduate with out of high school, and the expectations of skills and knowledge in the first year of college.

RPPs are particularly suited to address problems of this nature because, unlike top-down standards-based reforms, the inclusive working process of an RPP involves the very stakeholders upon whom district-level educational transformations will depend. An RPP is also nimble and capable of responding rapidly to change, such as by bringing in new researchers or practitioners to accommodate unexpected local challenges or opportunities and to support experiments aimed at meeting the needs of different teachers and different students.

Specific to the Encoding Geography pilot study, the RPP collaboration includes geographers and computer scientists who understand research, but have limited understanding of the practical side of schooling. On the flipside, there are educators with knowledge and expertise in curriculum development, learning, and meeting the needs of diverse learners, but who lack the disciplinary knowledge and know-how to conduct research (or even why they should teach something like geocomputation). The varied perspectives and experiences of this partnership informed the formulation of a Common Agenda consisting of four guiding principles:

a. **Continuous, reflective, and democratic learning**: In a diverse and complex RPP, it is essential for each member to adopt a purposeful mindset to listen and understand first and then seek to share their own ideas and perspectives. As the Encoding Geography RPP works toward short- and long-term goals for broadening participation in geocomputation, it will regularly revisit

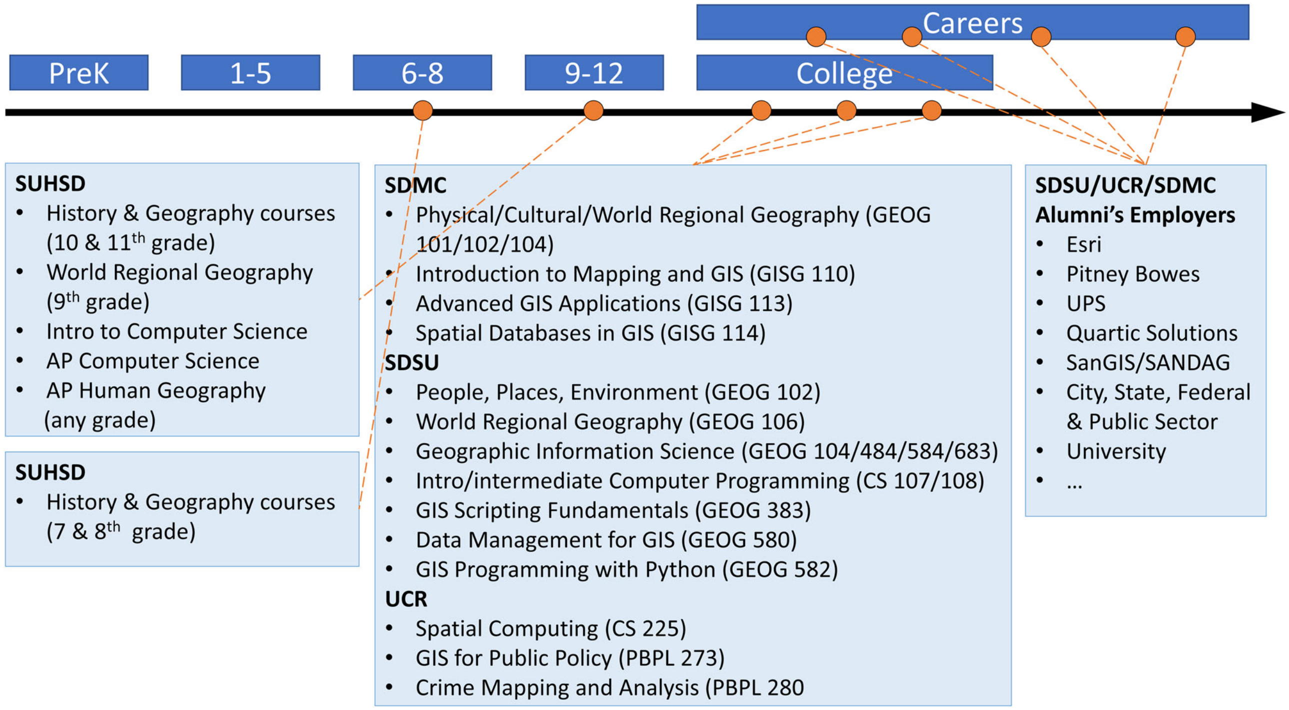

Figure 1. Geocomputation curriculum pathways to and beyond Sweetwater Union High School District.

progress toward shared objectives and expectations for future work. This means valuing balance and ensuring no one person or viewpoint dominates the RPP's discussions and decisions.

b. **Appreciate complexity of expertise**: The Encoding Geography RPP must recognize that research, instruction, and advocacy are different activities, and that geography and computer science education have their own priorities and challenges. The RPP therefore needs to utilize the experiences and expertise of each member and strive to make the RPP equitable in generating benefits for each party, working toward a common ground to build educational capacity for inclusive geocomputation. This means combining diverse experiences, expertise, and perspectives, while focusing on intersectionality (e.g., geography and computer science).

c. **Be strategic**: As the Encoding Geography RPP implements activities in California, it will maintain an outlook for building capacity for inclusive geocomputation in other states. To achieve scaling up and replication of the RPP over the longer term, it will be necessary for collaborating researchers and practitioners in other states to identify areas in school and university curricula where computational and geographic thinking can be introduced and integrated. The RPP will support these efforts by documenting how it took initiative to solve agreed-upon problems and developed measures by which to track progress, sustain relationships, and ensure a "win-win" outcome for all members of the community.

d. **Create curriculum resources and recommend instructional approaches that account for student, teacher, and disciplinary perspectives**: At the core of our project is the student and her or his welfare. The Encoding Geography RPP should therefore assist geography and computer science educators in their efforts to build student perspectives into the curriculum resources designed to broaden participation in geocomputational education and the workforce. This means the RPP needs to avoid assumptions about 'who' students are, and accordingly work to obtain contextual indicators of their beliefs, values, aspirations, and attitudes and how these vary for different groups (e.g., on the basis of socioeconomic status, gender, race/ethnicity, etc.). This will help the RPP make a case for the benefits of geocomputational education to diverse student populations.

Guided by this Common Agenda, the Encoding Geography pilot RPP started mapping the existing learning opportunities where geocomputational content can potentially be introduced and sequenced as a pathway toward geocomputationally intensive majors and careers (see Figure 1). Important considerations that arose during the pilot RPP project include the potential of some of the existing geography courses at SUHSD in terms of broadening participation. For example, according to the California Department of Education, the AP Human Geography course attracted over 18,000 learners in California in 2018-2019, of which 58.9% were women. In the same academic year, World Regional Geography courses attracted almost 35,000 learners in California, of which 47.6% were women. The World Regional Geography course also attracts an important number of English language learners, namely 5% of 9th graders.

The participating higher education institutions have also taken steps to expand access to geocomputation. For example, the GIS Associate of Science Degree at San Diego Mesa College now requires three credits of a programming language. At the University of California Riverside, a new

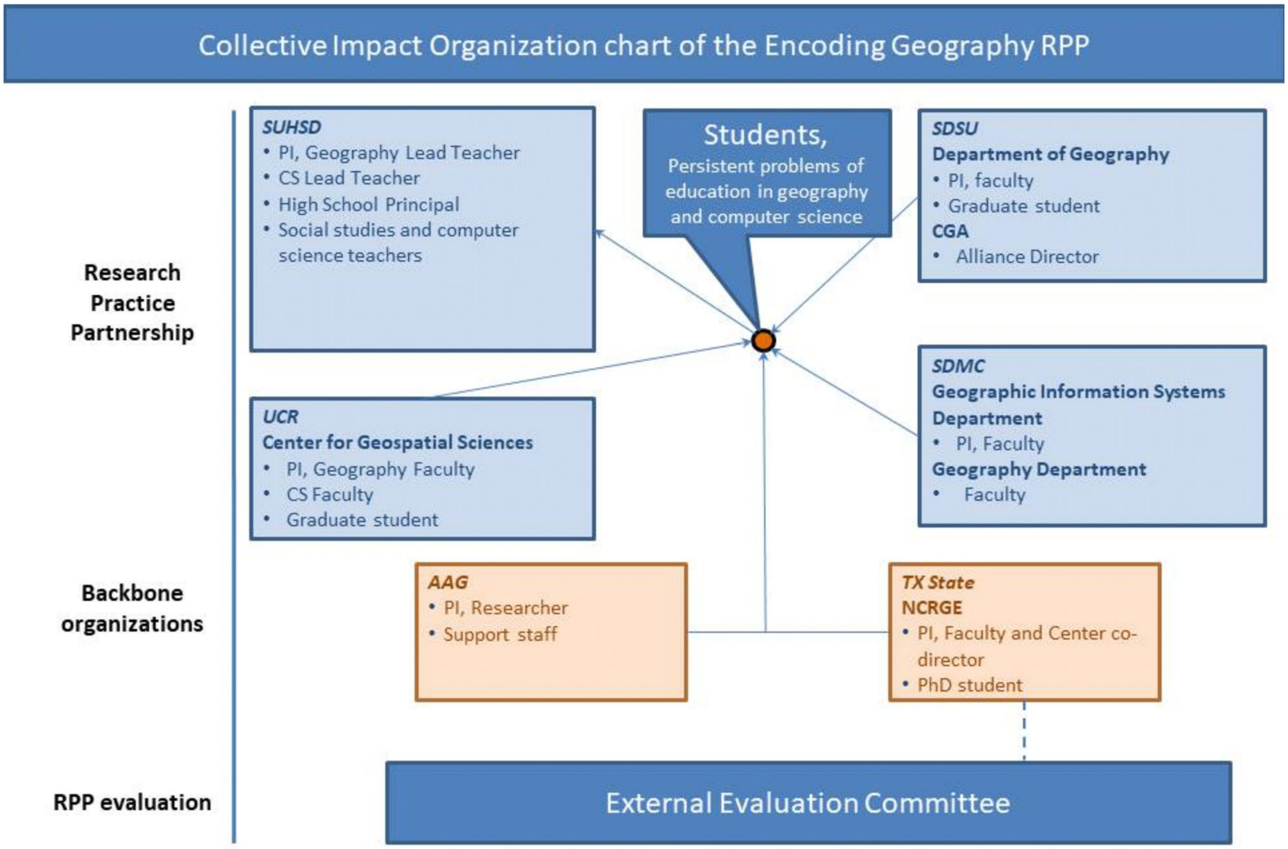

Figure 2. Collective impact organizational structure of the encoding geography RPP in Southern California.

course called "Spatial Computing" is offered by the Department of Computer Science and Engineering. In the Department of Geography at San Diego State University there is growing demand for courses to incorporate computational concepts.

Scaling up the encoding geography RPP (2021 – 2023)

With renewed support from the NSF CSforALL program,[2] the Encoding Geography RPP in Southern California is implementing a plan over three years to support development and evaluation of the curriculum pathway in the culturally diverse school districts and minority-serving institutions of higher education comprising the partnership (see Figure 2). The research goals, questions, and methods were collaboratively developed by RPP members consistent with the principles of its guiding Common Agenda. Five goals specify the aims of this work:

- Goal 1: Articulate the existing curriculum pathways from school to college to career and identify broadening participation challenges associated with each learning opportunity.
- Goal 2: Identify the specific knowledge and skills gap between geographers, computer scientists, and the geospatial technology industry.
- Goal 3: Capitalize on the expertise of the RPP members to formulate recommendations that strengthen existing pathways with culturally relevant pedagogy in geocomputation.
- Goal 4: Test inclusive geocomputational educational materials for secondary school and college students.
- Goal 5: Articulate a replicable Collaborative Impact framework for establishing Encoding Geography RPPs in other states.

In pursuit of these goals, the Encoding Geography RPP is committed to experimenting with new approaches to curriculum thinking and professional development aimed at helping teachers meet new demands on their practice and profession. According to a recent study by the National Academies, teachers are increasingly expected to (National Academies of Sciences, Engineering, and Medicine 2020):

1. Set teaching goals that require improved disciplinary content knowledge and culturally relevant pedagogy, while preparing students for the workforce by helping them apply content to novel problems and situations.
2. Create equitable learning environments that account for the greater diversity of students and the experiences they bring into schools.
3. Select subject matter and create instructional materials that support implementation of new curriculum standards in the context of their states and schools.

The trends in teaching and education identified in the National Academies report suggest that achieving the

Encoding Geography RPP's goals for inclusive geocomputation warrants more than redesigning the curriculum (e.g., by identifying 'points of intervention' in existing curriculum where geocomputation can be introduced). The broadening participation challenge facing the RPP goes beyond simply ensuring that subject matter resembling geocomputation is 'present' in a curriculum serving a diverse school district. Curriculum design must also attend to the epistemic qualities of the subject matter of geocomputation and the related challenge of making this subject matter accessible to different groups of students. The RPP will do this by encouraging geocomputation educators to think in terms of powerful knowledge (Young et al. 2014) and how teaching geocomputation in schools, as a matter of social justice (Biddulph et al. 2020), might contribute to "what people are capable of doing, thinking, or achieving and what freedom this affords them to live life in the way that they choose" (Bustin 2019, p. 100).

Asking educators to focus on capability-based learning goals is intended to encourage knowledge-led curriculum making in geocomputation that recognizes the domain-specific character of learning. Although this might seem ambitious for the perceived technical nature of geocomputation, it is important to remember that geocomputation is about more than coding, programming, and spatial analysis with geospatial technology. Encoding Geography's vision for inclusive geocomputation is for all young people to acquire disciplinary knowledge in both geography and computer science so that they gain capacity to think like a geographer and computer scientist at the same time.

Data-driven curriculum making to broaden participation in geocomputation

The Encoding Geography RPP recognizes the importance of having a multilayered strategy for broadening participation that connects emerging geocomputational curriculum to, among other things, co-curricular support services, mentoring, experiential learning, and financial aid to lower the costs of postsecondary education (Estrada et al. 2018; McDaris et al. 2019, James and Singer 2016). Indeed, the collaborating organizations in the RPP have existing institutional supports of this nature that can be leveraged over time to expand opportunities for students who wish to pursue education and training in geocomputation.

Before this can happen, the RPP needs to design and develop something that currently does not exist: an inclusive curriculum pathway that foster students' aspirations toward courses, majors, and careers in geocomputation. Prior research in broadening participation in science offers the RPP some guidance. There is, for example, convincing evidence that conveying the relevance and applications of science is a pedagogically effective strategy for improving student attitudes that associate positively with career choice and further education in science (e.g., interest in science, confidence to do science, and perceived utility of science) (Sheldrake, Mujtaba, and Reiss 2017). This implies an inclusive curriculum for geocomputation will require teachers who understand 1) what makes geocomputation relevant from the student's perspective (everyday life), and 2) the applicability of geocomputational knowledge and skills for college, careers, and civic life (wider contexts). It further implies a role for the researchers to acquire data that helps the partnership understand the importance of student aspirations and attitudes in the process of curriculum design.

To put these ideas into practice, the Encoding Geography RPP will implement a curriculum approach known as "Powerful Geography".[3] Developed by the National Center for Research in Geography Education through a series of research workshops with geography and social studies coordinators, the Powerful Geography approach aligns with recommendations by curriculum theorists including Wesley Null (2017) and Zongi Deng (2018) who argue that a curriculum's liberating potential depends on teachers thinking for themselves while accounting for the students they teach. It is also consistent with calls to abandon top-down standards-based reforms in favor of investments aimed at improving district-level outcomes through local experiments in curriculum and instruction (Loveless 2021).

The Encoding Geography RPP will apply the Powerful Geography approach in professional development that prepares participating educators to convey the relevance and applications of geocomputation at various points along the curriculum pathway (Figure 3). Two data sources will guide the local curriculum making by geography and computer science teachers. First, educators in the partnership will be trained to collect data on students' life and career aspirations using a questionnaire adapted from a Powerful Geography study involving undergraduate students in an introductory geography course (Larsen et al. 2021). Students completing the questionnaire indicate their preferences and interests related to major occupational areas (e.g., transportation, environment, public safety, military, business, agriculture, etc.) and various social and environmental issues.

After the aspirations data are collected, the researchers in the partnership will interview professionals whose backgrounds in geocomputation align with those aspirations and attitudes. From these individuals we will identify authentic applications of geocomputation and the types of geographical questions those applications were designed to address. These practices will serve as the basis of teacher-generated learning activities designed to help students recognize and value the relationship of geocomputation to life beyond or after school (cf. National Research Council 1996; Pattengale 2009). Drawing on the knowledge of geocomputation professionals in the design of the RPP's professional development activities directly supports the President's Council of Advisors on Science and Technology (PCAST) recommendations that STEM teachers should have "enough content knowledge to link STEM to compelling real-world issues, model the process of scientific investigation, effectively address student misconceptions, and help their students learn to reason and solve problems like mathematicians, scientists, and engineers" (Committee on STEM Education 2013, p. 18).

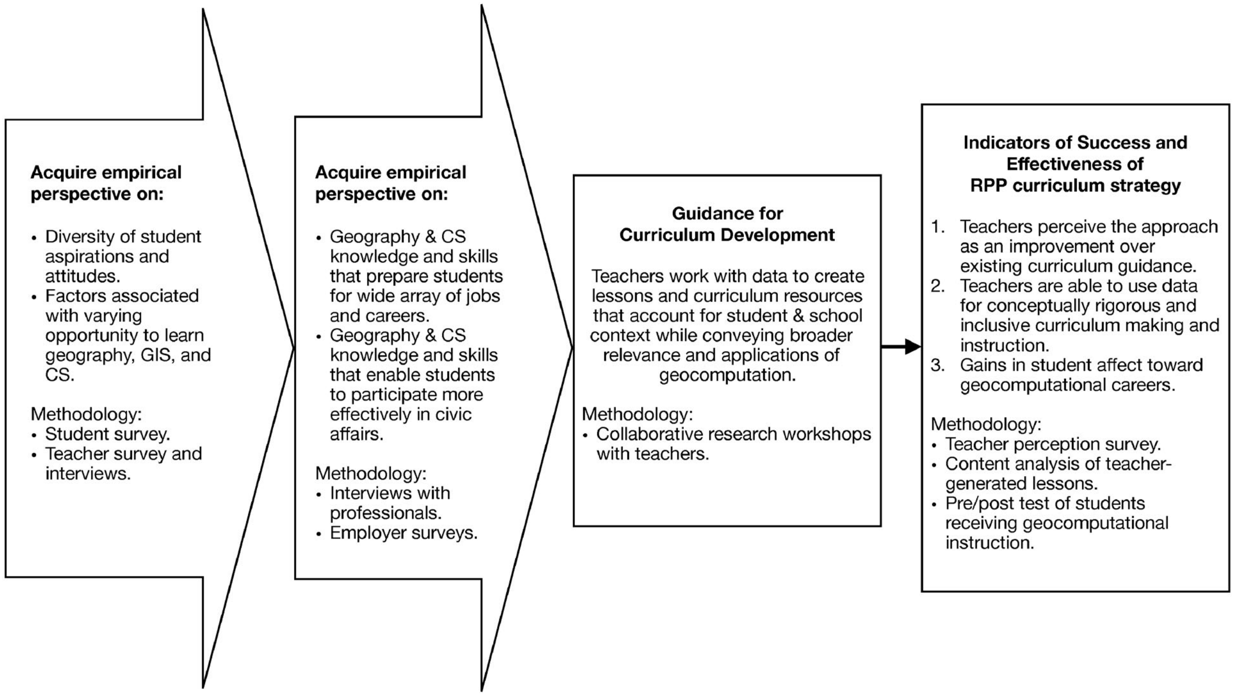

Figure 3. Powerful geography curriculum approach.

As the teacher-generated lessons and resources are piloted in the curriculum pathway, researchers will collect data to provide measures of the partnership's success in achieving goals for inclusivity. This will include monitoring potential shifts in school and college educators' awareness of and attitude toward computational thinking and geography, and how they think these relate to the courses they teach. Researchers will also gather data to gauge the extent that student aspirations and attitudes toward geocomputation change over time, through a phased approach that gathers student affect data prior to, during, and following exposure to the geocomputational curriculum resources. If the partnership observes gains in attitudes such as students' interest, perceived utility, and confidence, then the empirical case for the curriculum approach as a broadening participation strategy will be strengthened.

Conclusion

The Encoding Geography RPP will lay the foundation for a replicable strategy to broaden participation in geocomputational education and careers. Applying Powerful Geography as a curriculum strategy for broadening participation in geocomputation complements the ideas of contextualized, localized, and culturally relevant pedagogy while paying special attention to the need for student validation using an asset-minded approach to minority youth (Gay 2013; Howard 2001; Paris and Alim 2017; Schön 1987; Shade, Kelly, and Oberg 1997; Young, Young, and Ford 2019). The RPP collaboration is an example of how piecemeal efforts toward curriculum innovation and institutional change can simultaneously affirm students' desire to serve their own communities and the wider society (Rendón, Kanagala and Bledsoe 2017). As such, the partnership is motivated to discover highly engaging educational practices that ameliorate persisting gaps in geography achievement as documented by the National Assessment of Educational Progress (NAEP) (Solem 2021).

Future activities to establish RPPs for geocomputation elsewhere in California and the United States will advance educational capacity for a new generation of "computational geographers." These diverse graduates will be better equipped to contribute to the national innovative ecosystem and face the challenges associated with spatial big data alongside current social and environmental challenges such as climate change and international migration crises. Broadening the participation of women and minorities in geocomputation courses will realize the presently untapped potential for innovation and productivity in the field.

While this RPP is clear in articulating the need for geocomputational thinking and skills to satisfy demands and opportunities in postsecondary education and the workforce, the project also strives to empower educators to communicate a rationale for geocomputation as a worthwhile component of a student's education. This is an important undertaking because no subject has an automatic right to be part of a school's curriculum (Lambert and Solem 2017). In acknowledging educators' responsibility and agency for constructing a curriculum appropriately suited to their students, developing educators' own disciplinary knowledge and curriculum leadership will be essential, a conclusion echoed in the most recent iteration of the GeoCapabilities project (Biddulph et al. 2020).

The RPP welcomes correspondence from readers in response to this commentary.

Notes

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2. NSF Awards CNS-2031380, CNS-2031418, and CNS-2031407
3. www.powerfulgeography.org

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