YouthQuake: Engaging urban students in a computational geology experience to forecast earthquake hazards and manage risk for their community

This *Developing and Testing Innovations* project will engage Hispanic and African American middle school students in an urban California school district in computational geoscience investigations using innovative block-based coding and visualization technologies to explore earthquake hazards, risk, and preparedness for their community.

Importance

Earthquakes threaten communities in California. There are over 500 active seismic faults in California. Most Californians live within 30 miles of one, putting them at risk of experiencing impacts from an earthquake [1]. Despite the risk, less than half of Californians are prepared for such emergencies [2]. Earthquakes can wreak havoc on infrastructure, cause casualties, and disrupt vital services. To try to reduce potential loss of property and life, scientists conduct risk assessments. This work of identifying vulnerable communities and assessing earthquake likelihood and impacts belongs to computational geoscientists who make sense of large-scale seismic, geographical, and socioeconomic datasets.

Geoscience professionals use computation for earthquake forecasting and risk assessment. Geoscientists use technology in various ways—from collecting large amounts of data to developing computational models to simulate the real-world phenomena they are studying. Earthquake research, like other topics in Earth science, requires sophisticated instruments such as remote sensing satellites [3], [4], land stations, and seismic and Global Positioning System (GPS) stations. As data from these instruments become more robust and computers become more powerful, the rise of computational practices in geoscience research and careers is also accelerating.

School science learning *can* mirror the advances in computational geoscience. If taught in a way that reflects how scientists investigate earthquake hazards and risk, students could have the authentic opportunity to experience innovative uses of computational technology based on real-world datasets. Students could also develop computational reasoning skills associated with geoscience practices to explore complex Earth science problems [5].

Authentic, community-relevant computational experiences can broaden participation of diverse students in geoscience. The geosciences have the lowest Hispanic and African American representation of all the science, technology, and engineering disciplines [6]–[9]. The less diverse a field, the less welcoming it is to individuals who have been historically kept furthest from opportunities [10]. This means that for Hispanic and African American students it is difficult "seeing themselves" doing this work [11]. It has been shown that when motivation, emotion, and a connection to the Earth are combined, students show a greater interest to the content [12], [13]. These bridging elements are critical when educating students from Hispanic and African American communities and could impact their ideas about geoscience career opportunities. For students in California, the authentic exploration of earthquake hazards and risk, carried out with similar methods and tools as scientists, provides a powerful context to connect in-school learning with elements of daily life that are personally meaningful and that exist outside of school. The notion of "connected science," i.e. a bridging of the science represented in classrooms with content from communities [14], [15], has been found to help students see how the practice and knowledge learned in schools are relevant to the world in which they live [14].

Addressing equity in science class can begin by prioritizing students' knowledge, personal experiences, and community values. Students' STEM interests continue to evolve through in-school, out-of-school, and at-home experiences as well as through interactions with adults [16]. According to social practice theory [17], students' career aspirations are shaped by a myriad of factors (e.g., personal and family backgrounds, participation in science-related activities, and perception about self in science and scientists' work). Although in-school science experiences have the potential to shape students' career aspirations in STEM, they do not necessarily leave positive images of science, scientists, or science careers for students from the populations underrepresented in science [18]. While the traditional view of science class elevates disciplinary knowledge, the current science-as-practice framework [19], [20] encourages students' legitimate participation in science practices to shape their learning of disciplinary core ideas [21]. In that learning process, students as epistemic agents are expected to find their own voices and actively seek to contribute. However, this can only happen in an open and safe learning environment governed by a classroom community that holds shared goals and norms. Further, urban youth with Hispanic and African American backgrounds can benefit from exploring real-world problems their communities are facing as contextual scaffolds to bridge student interests and science learning [14].

Project Goals and Objectives

The goal of this two-and-a-half-year project is **to engage Hispanic and African American middle school students in authentic computational geoscience investigations of earthquake hazards in order to increase their interest in, and identity with, computational geoscience careers.** In the NSF-funded GeoCode project, we demonstrated how computation can be integrated with science practices (i.e., computation-mediated science practices) so students can find patterns in large data sets and model seismic hazards and risk. (See Results from Prior NSF Support). Extending from the prior work, the *YouthQuake* project will create an inclusive, personally meaningful technology experience that engages diverse students in the exploration of earthquake hazards and risk. The work will be done through a partnership of the Concord Consortium, UNAVCO, the San Joaquin County Office of Education's FabLab, geoscientists from the University of South Florida, and teachers and students in urban middle schools in Stockton, CA, located in San Joaquin County.

Middle school is targeted because it is during these formative years that students begin to lose interest in science while at the same time form cultural identities and career aspirations [22]. Moreover, for most students, middle school is the only guaranteed time when Earth science is taught, according to CA state standards [23]. To broaden participation among Hispanic and African American students, the project will work with 5 middle schools in Stockton, CA (see Table 1). (Note California uses Hispanic when collecting data about school demographics. For this proposal, we will use Hispanic when referring to the Hispanic and Latinx community.) The objectives for this project are:

	Fillmore	Hong Kingston	Rio	Bush	Spanos
Economically disadvantaged	92%	76.1%	76.1%	78.9%	96.8%
African American	3.5%	10.3%	5.9%	8.7%	3.0%
Hispanic	85.0%	64.6%	41.2%	35.3%	90.3%
Asian	4.2%	10.3%	36%	36.3%	3.9%
White	5.0%	3.7%	4.3%	3.2%	0.9%
Other	1.0%	4.7%	8.3%	10.3%	0.7%
Two or more races	2.0%	6.4%	4.2%	5.7%	1.2%

Table 1. Demographic statistics for schools participating in YouthQuake

Objective 1: Develop a partnership to co-design curriculum that engages Hispanic and African American middle school students in computational geoscience investigations about earthquake hazards and risk to increase their computational geoscience interest and identity. The partnership is composed of teachers, geoscientists, educational researchers, technology and curriculum developers, a professional development specialist, and a workforce and diversity specialist. Each will bring their own expertise and perspective to the design and evaluation of the *YouthQuake* curriculum.

Objective 2: Develop *YouthQuake* curriculum. The partners will develop a four-week computational geoscience curriculum that consists of three units, each taking approximately one week of in-class time, and a one-week student independent summative project. The entire curriculum will include an additional 10 hours of out-of-school activities to gather data (e.g., interviewing community members). The units will be situated in the community context as students 1) explore their neighborhood's likelihood of experiencing a damaging earthquake and related preparedness, 2) investigate GPS data and use computational models of land motion along the faults around their community, and 3) create computational visualizations of earthquake hazard maps. In each unit, students will have opportunities to talk with diverse geoscientists and undergraduate students about geoscience jobs and experiences so that they can connect what they are doing in the classroom to real jobs.

Objective 3: Conduct research. Two cycles of design-based research will be conducted using a mixed-methods design combining various qualitative and quantitative data sources such as tests, surveys, embedded assessments, and whole class and student videos. During the design research phase, the partners will co-develop the materials, critically review enactment results, and generate knowledge about curriculum design and teaching strategies that promote students' engagement with computation-mediated science practices as well as computational geoscience identity and career interests

Objective 4: Strategically disseminate the project materials to other local districts and disseminate project findings and materials to the field. The project will publish and presen research at national conferences and highly rated research journals, disseminate frameworks and project resources to teachers and professional development groups, and release materials for free use on the Concord Consortium and UNAVCO websites.

Results from Prior NSF Support

Integrating Transdisciplinary and Computational Approaches in the Earth Science Curriculum Using Data Visualizations, Scientific Argumentation, and Exploration of Geohazards (GeoCode). *(PI: Pallant; Co-PIs: Connor, Charlevoix, Lee, Paessel; DRL-1841928; $1,978,274; 8/15/16-9/30/23).* GeoCode developed the GeoCoder, a block-based programming workspace connected to a map or data-based visualization. We developed two online modules exploring volcanic and seismic hazards. Fifty-three teachers implemented the modules with 2,384 middle and high school students across 14 states. We developed assessment instruments to measure students' computational reasoning associated with the scientific investigations of hazards and risk. Students made significant pre-test to post-test improvements on computational reasoning in the tephra volcanic module ($n = 200$, ES = 0.85 SD in Cohen's d, $p < 0.001$) and in the seismic module ($n = 202$, ES = 0.97 SD in Cohen's d, $p < 0.001$). ***Intellectual merit:*** The project has created novel learning opportunities that can lead to enriching science and computation learning in authentic computational geoscience contexts. ***Broader impacts:*** The project equipped students with the experience of computation-mediated science practices applicable to future learning endeavors and greater knowledge of how science research can inform society about hazards and their impacts. ***Publications*****:** Three published journal articles [24]–[26]; 3 newsletter articles [27]–[29]; and four conference presentations.

Geological Models for Explorations of Dynamic Earth (GEODE) *(PI: Pallant; Co-PIs: Lee, McDonald; DRL-1621176; $2,698,654; 8/15/16 – 7/31/22)*. GEODE developed two software tools: (1) Seismic Explorer, an interactive earthquake data retrieval and visualization tool, and (2) Tectonic Explorer, an interactive three-dimensional dynamic simulation of plate interactions. Using these two tools, we developed a plate tectonics module focused on the big idea that the Earth's surface is a system of simultaneously and continuously interacting tectonic plates interacting on all sides of their borders. We also developed an assessment instrument to measure student understanding of plate tectonics from the mechanistic reasoning perspective (Cronbach alpha = 0.88). Analysis of students who completed both the pre-test and post-test (n = 619) showed that students made significant gains on that instrument by 0.92 Standard Deviation (SD), $p < .001$. We also characterized different levels at which students expressed sequential reasoning in plate tectonics and discovered that students' use of the Tectonic Explorer was in part responsible for their sequential reasoning. ***Intellectual merit*:** This project has contributed to the field's understanding of how engaging students with plate tectonic simulations supports their learning about Earth's surface and sub-surface processes from the system perspective. ***Broader impacts:*** The GEODE project has been used by over 22,540 students and 600 teachers from diverse school settings serving students with varied socioeconomic, racial, and ethnic backgrounds. ***Publications**:* Five published journal articles [30]–[34]; 6 submitted articles [35]–[40]; 7 newsletter articles [28], [34]–[38]; 14 conference presentations; and 1 doctoral dissertation [46].

Narrative Modeling with StoryQ: Integrating Mathematics, Language Arts, and Computing to Create Pathways to Artificial Intelligence Careers *(DRL-1949110, $1,496,893, 2020-2023, PI: Chao, Co-PIs: Finzer, Rose, and Jiang).* This project has been developing and researching curriculum modules with StoryQ, a web-based text mining and machine learning environment. The project introduces high school students to core artificial intelligence (AI) concepts, roles and responsibilities of AI developers, and AI-powered career opportunities. ***Intellectual merit*:** Multiple classroom pilots demonstrated the positive impacts of this approach on students' understanding of AI concepts, practices, and career interests. ***Broader impacts*:** This project has been developing a scalable solution to AI education—engaging students in machine learning practices by leveraging their knowledge of language and culture. This approach can be implemented in foundational computer sciences, English Language Arts, and history classes, hence has the potential to reach a much wider audience than advanced computer science classes. ***Publications*:** One published journal article [47]; 1 magazine article [48]; 6 conference presentations, 1 completed PhD dissertation [49]; and 2 newsletter articles [50], [51].

Theoretical Foundations

Pillar 1: Innovative Use of Technology in Teaching and Learning. *A Framework for K-12 Science Education* [5] emphasizes the importance of students experiencing disciplinary core ideas through relevant science practices that reflect the ways scientists conduct their research. This type of authentic science learning can be achieved by engaging students in the practices of scientists [5], [52], [53] with the use of professional resources, tools, and data [54], [55] and by addressing contexts relevant to students' everyday lives [52]. Authentic engagement with science and technology can improve student motivation, science learning, and epistemological understanding [56]. However, authentic science is not readily accessible to most students [57] because it is difficult to translate scientists' resources and tools into something that is appropriate for students' level of understanding in the science topic, abilities to carry out practices, and epistemic commitments [21]. The classroom-workplace gap results in a missed opportunity. To investigate earthquake hazards and risk, students can benefit from conducting scientific investigations using real-world data similarly to the way scientists do their work. The proposed project will, therefore, follow the computational practices of the geoscientists who conduct earthquake risk assessment, including (1) accessing and visualizing large datasets and (2) simulating and visualizing earthquake hazards and risk based on land deformation.

To integrate computation into geoscience investigations for middle school students, we apply the following four design principles. First, students will leverage the power of computing to explore regularities in nature despite its complexity. Computational models are defined by a set of variables where each variable can be isolated to explore its effect on the outcome of the complex system [58]. Second, students' investigations will be framed around computational geoscience problems relevant to their neighborhoods. In this way, students' computational investigations will be in service of solving problems for communities, rather than completing computational tasks just for the sake of doing them [19], [20]. Third, creation and interpretation of visualizations will be situated in the computational geoscience problem-solving context [59]. Critical to answering geoscience problems is the ability to create visualizations that are configured to reflect how geoscientists make sense of geospatial data. We will orient the need for these visualizations as central to both understanding disciplinary content and articulating computational reasoning needed to carry out an investigation. Finally, students will be scaffolded to use computation as they progress [60], and coding will be streamlined to facilitate student engagement. As students' disciplinary knowledge and computational reasoning improves, during the *YouthQuake* curriculum enactment, they will be guided to access more powerful data and modeling tools for more complex problems.

Pillar 2: Partnership. Co-designing the student learning experience with partners that have distributed expertise [61], [62] is intended to initiate the proper centering of the perspectives of cultural groups and communities [63] that are underrepresented in science in general and geoscience in particular. The intention is explicitly to *build together* the processes and norms of collaboration so that partners can identify ways that engage students with innovative technology as well as contextual scaffolds that bring community relevance. In doing so, the partners aim to disrupt the status quo where educators are handed educational materials researchers design for the purposes of testing materials [64], [65].

Figure 1 represents the *YouthQuake* partnership model with a collaborative theory of action. The teachers are educational experts and will bring their knowledge of the classroom context and the pedagogy suited to address diverse students in the classroom as well as an understanding of the parents/guardians of these students. The scientists will provide the disciplinary and professional career expertise. The educational researchers will investigate students' experience with the *YouthQuake* curriculum in terms of personal meaning, community relevance, epistemic engagement, and computational geoscience identity. The professional development leader has experience providing science and engineering learning experiences to the teachers and students in communities and will help ensure that the *YouthQuake* curriculum aligns with the community's perspectives. The workforce diversity specialist will focus on the effort the geoscience community is making to increase awareness of and opportunities for diverse populations in the field. The curriculum and technology developers will bring their design knowledge and experience to create a technology-rich learning environment with

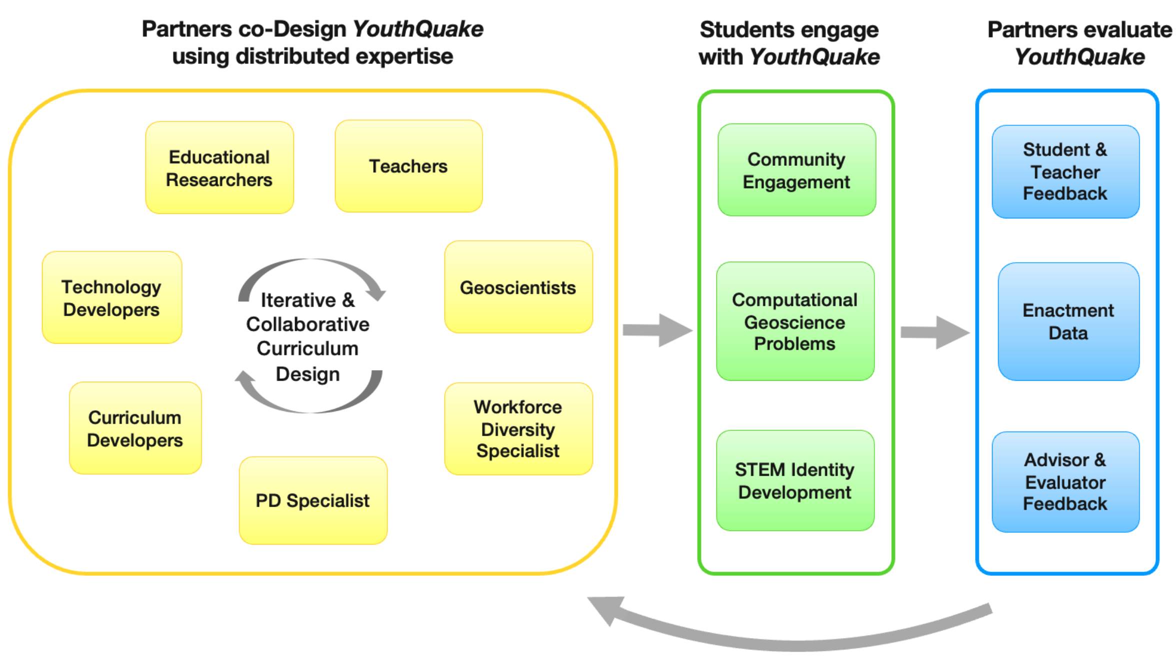

Figure 1. The YouthQuake partnership model.

computational geoscientific tools. The students will engage in the computational geoscience investigations featured in the curriculum while bringing the knowledge, values, and experiences from their lives and from their community. Based on analysis results and feedback from students and teachers as well as from advisors and the evaluator, the partners will engage in revisions and redesign of the curriculum.

The goals of the co-design process are to develop a curriculum that builds bridges between students' personal meaning and their perceived value of computational geology careers [14]. Throughout the project, the partners will 1) negotiate multiple perspectives, 2) participate in the iterative curriculum design decisions, 3) learn from students' enactment of the material [65], and 4) analyze data and revise materials [66].

Pillar 3: Strategies for Equity in STEM education. The strategies for how the *YouthQuake* project will design materials to provide equitable STEM learning opportunities are described below.

Strategy 1. Use contextual scaffolds that bridge real-world problems with students' diverse forms of science knowledge and experiences. We use contextual scaffolds to mean elements from life experiences that serve to connect new knowledge and experiences to older, more articulated social experiences. Contextual scaffolds can provide Hispanic and African American students with meaningful and intellectual science learning opportunities [14]. When programs intentionally connect STEM to relevant issues in a community and youth's cultural backgrounds, equitable STEM learning opportunities are expanded [5]. Investigations of earthquake hazards and risk can offer a rich learning opportunity because they (1) have no clear correct answers, (2) are interdisciplinary, (3) are relevant to learning standards, (4) are of interest to students' lives, and (5) can be contextualized to their communities [14]. The *YouthQuake* curriculum will guide students to explore local earthquake risk and incorporate information from their families and communities' risk knowledge and preparedness.

Strategy 2. Engage students in authentic investigations and practices of career professionals. Weaving authentic science investigations with students' cultural worldviews and experiences can increase student interest [67] by providing context and meaning [68]. The *YouthQuake* curriculum will introduce authentic science resources and tools to observe and interpret Earth processes in the way geoscientists do [69]. In studying earthquakes, geoscientists must render complex GPS and seismic data into visualizations for analysis [70]. The *YouthQuake* curriculum will support students to integrate geographically relevant history about earthquake events, earthquake hazards and impacts, with community knowledge about mitigation options and preparedness. Thus, students will apply their own knowledge, experience, and values to data-based explorations, simulations, and visualizations in the *YouthQuake* curriculum. Being involved in authentic geoscientific computational investigations can help students see themselves work in the profession [71].

Strategy 3. Reflect cultural assets of student communities. It is important to build on students' cultural assets and strengths and to encourage the expression of their needs, interests, and opinions [72]. With this type of personally relevant material, educators can utilize the cultural characteristics, experiences, and perspectives of diverse students as conduits for teaching more effectively [73]. When situated within the lived experiences of students, their science knowledge and practices become more personally meaningful, are more appealing, and are learned more thoroughly [74]. For Hispanic and African American youth, the effectiveness of learning activities depends in part on the activities' endorsement of communal goals and commitment to supporting the lives of individuals in their communities [75]. The *YouthQuake* curriculum will situate seismic science as a local issue that prioritizes places, people, and assets familiar to the students [76].

Strategy 4. Provide opportunities for students to exercise epistemic agency in shaping their knowledge through computation-mediated science practices. Students' in-school, out-of-school, and at-home science experiences contribute to their views of current and future selves in science careers [71]. One way to empower students' voices and identities in science classrooms is to use science-as-practice in an open-ended, authentic disciplinary context [77], [78]. In such a context, students carry out science practices in ways that are appropriate for their questions [79]. As students are likely to take diversified pathways at their own pace, they must be at the center of their own learning, becoming epistemic agents [20]. In support of such development, teachers are expected to act as supporters and guides so that students' pursuits can be more productive and more sophisticated [80]. In this science-as-practice view, both students and teachers negotiate cognitive authority in the classroom community [81]. In the pursuit of sharing and improving knowledge and practice, students are expected to be cognizant users of tools and materials as well as active participants in the community the class has created [82]. As part of *YouthQuake*, students will engage in open-ended authentic investigations in which they actively model, forecast, and prepare for the possibility of a future earthquake impacting their own community.

Technology and Curriculum

The resulting innovative technology and computationally integrated *YouthQuake* curriculum will be aligned with the standards identified in *A Framework for K-12 Science Education* [5] which is the foundation for the Next Generation Science Standards [83]. Below we describe the technology, the standards alignment, and the curriculum.

Innovative Technology. Scientists and those in industry that conduct risk assessments rely heavily on computationally intensive approaches [84], [85]. To enable students to model and assess risk through computation [86], this project builds on a mature technology, the ***GeoCoder*** (Figure 2). To develop GeoCoder, we integrated scientific-grade computer programs used by geoscientists and professionals to a block-based computer programming technology called Blockly. Block languages such as Scratch and Blockly are commonly used to teach K-12 students to code because the blocks simplify the syntax typically associated with programming languages and the shapes give clues on how programming ideas are combined [87]. In the GeoCoder, specific content blocks are created to enable authentic investigations of geoscientific topics. In addition to traditional blocks such as loop and data blocks, new blocks were created including "Filter GPS stations" and "Display GPS velocity vectors." The Blockly-enabled programming space is combined with a map-based visualization space so that students can create, view, and interpret the computational outputs generated from running a program. The GeoCoder is designed for middle and high school students. *YouthQuake* will add location-specific maps and new computation blocks needed to carry out investigations in the *YouthQuake* curriculum.

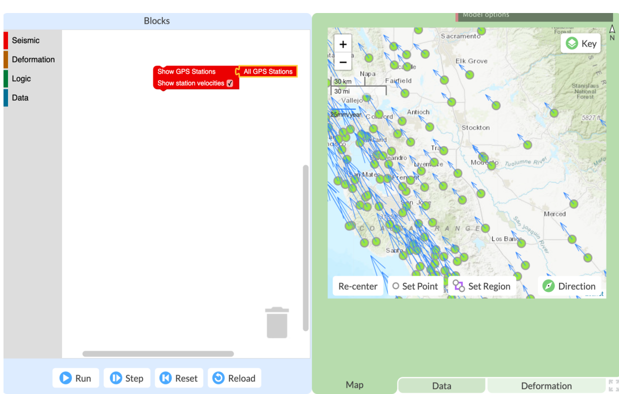

Figure 2. The GeoCoder showing programming space on the left and GPS locations near Stockton on the right.

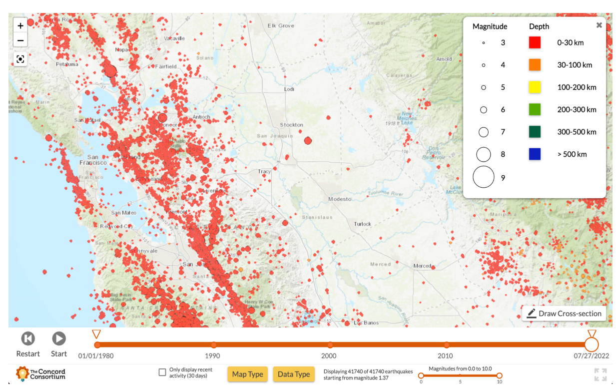

Figure 3. The Seismic Explorer showing the number of earthquakes that occurred near Stockton between 1980 and the present.

Seismic Explorer is a visualization tool of real-world earthquake, volcanic eruption, and plate motion data (Figure 3). Students use Seismic Explorer to display the data at any time point or any duration from 1980 to the present, zoom in and out of the visualized data, and look for earthquake, volcanic eruption, and landform patterns in relation to plate locations on Earth's surface. By examining cross-sections, students can also investigate earthquake depth patterns along faults.

YouthQuake Curriculum Alignment with Standards.

Disciplinary Core Ideas related to Earth and Space Science

ESS2.B: Earth's Systems: Plate Tectonics and Large-Scale System Interactions. "The plates move across Earth's surface...producing earthquakes and volcanoes..." [5, p. 182].

ESS3.B: Natural Hazards. "Earthquakes, in contrast, occur suddenly; the specific time, day, or year cannot be predicted. However, the history of earthquakes in a region and the mapping of fault lines can help forecast the likelihood of future events" [5, p. 193].

Science Practices

Analyzing and Interpreting Data: "...data must be presented in a form that can reveal any patterns and relationships and that allows results to be communicated to others. Because raw data as such have little meaning, a major practice...is to organize and interpret data through tabulating, graphing, or statistical analysis. Such analysis can bring out the meaning of data—and their relevance—so that they may be used as evidence" [5, p. 61].

Using Mathematics and Computational Thinking. "Computational tools enhance the power of mathematics by enabling calculations that cannot be carried out analytically. For example, they allow the development of simulations, which combine mathematical representations of multiple underlying phenomena to model the dynamics of a complex system. Computational methods are also potent tools for visually representing data, and they can show the results of calculations or simulations in ways that allow the exploration of patterns" [5, p. 64].

Crosscutting Concepts

Patterns. "The ways in which data are represented can facilitate pattern recognition and lead to the development of a mathematical representation, which can then be used as a tool in seeking an underlying explanation for what causes the pattern to occur" [5, p. 86].

Defining Computational Reasoning as Computational Thinking (CT) Expressed in the Computational Geoscience Investigations. Since Wing [88] advocated for the inclusion of CT as part of formative educational experiences in schools, many have attempted to operationalize CT [89]–[91]. Despite the lack of consensus, CT is largely: (1) associated with identifying and solving real-world problems, (2) often related to complex systems and systems thinking, (3) involving calculations to process data and visualizations to interpret data, and (4) prioritizing efficiency and optimization, usually achieved by algorithms through computational means. Since CT is multi-faceted, it is impossible for the four-week curriculum to address all of the above. Similar to Weintrop et al. [91], we instead situate CT in the science practices carried out as part of the geoscientific investigations in the *YouthQuake* curriculum where computation becomes a main method of accessing, collecting, analyzing, modeling, and visualizing data. We use computational reasoning (CR) to represent CT situated in the computational geoscience investigations and elicited when students engage in the following practices:

1. Assemble code blocks to plot GPS data points over time to determine how land moves around a seismically active tectonic boundary.
2. Assemble code blocks to run a deformation simulation to investigate how plate movement and friction affects earthquake frequency and intensity.

3. Assemble code blocks to compute and visualize the likelihood of future earthquake hazards based on the amount of deformation, the amount of friction along the fault, and community locations relative to the fault.
4. Predict the location and timing of future earthquakes using historical earthquake data.
5. Identify vulnerabilities in the community and mitigation strategies using computational outputs and community population and resource maps.
6. Assemble block codes to develop community asset maps based on the data from community stakeholders (family members, business owners, town council, etc.).
7. Create hazard awareness materials (e.g., pictograms) incorporating earthquake hazards, preparation, and mitigation strategies using computational outputs and other community data.

The *YouthQuake* Curriculum. The *YouthQuake* curriculum will highlight geoscientific thinking and computational reasoning when students engage in computational geoscience investigations required for conducting an earthquake hazards and risk assessment of their community. The UNAVCO partners will coordinate with teachers to arrange Zoom sessions that bring together professional geoscientists and undergraduate students with demographic backgrounds similar to the students. The guest speakers will have earthquake-focused careers, and the undergraduate students will share their experiences of pursuing careers in geoscience. Below is the overall and initial sketch of the *YouthQuake* curriculum. The actual community contextualization and the details of the students' computational geoscience curriculum will evolve as a result of the partnership co-design work.

Unit 1: What does earthquake history tell us about earthquake likelihood? How might measuring land movement be related to earthquake preparation? In California, an earthquake measuring 7.0 or greater, colloquially referred to as the Next Big One, is likely to occur in the next 30 years [2]. Using this to frame the likelihood of a future risk, the first unit will ask students how they personally perceive the risk of a devastating earthquake for themselves and their community. Students will create visualizations of U.S. Geological Survey (USGS) earthquake locations, magnitudes, and frequencies in California in general and their city specifically using Seismic Explorer (Figure 3). This data will help students consider the likelihood of an earthquake damaging their neighborhood. Students will grapple with the connection between hazards and impacts in terms of how socioeconomic status and race may affect an individuals' preparation, response to warnings, perception of risk, and evacuation decisions [92]. Students will learn from and talk to scientists and engineers who monitor land movement using GPS and use code to plot GPS stations in California and around Stockton (Figure 2). Student groups will interview community members and use the data to create a community asset map (a document of a community's existing resources, including institutions, individuals, and citizen associations) in order to identify local resources that make their community resilient to the impacts of a future earthquake.

Unit 2: How does computational data modeling visualize land deformation? How is modeling of the earthquake cycle used to understand earthquake magnitude and frequency? Students will analyze an earthquake potential map and consider how this map shows the likelihood of a damaging earthquake. Students will explore the movement of land through GPS data collected over time and compare the movement of GPS stations on both sides of the San Andreas fault. Students will also investigate data from GPS stations in and around Stockton. Students will use code to model land deformation and the resulting buildup of energy along faults and investigate how friction and rate of movement along a fault affect earthquake magnitude and frequency. Students will discuss their own experiences and interview community members about their earthquake experiences and preparedness. They will also talk to scientists at the USGS who developed the "Shake Alert" phone app that warns people about earthquakes before they occur. Finally, students will brainstorm how best to communicate warnings and preparations to their communities.

Unit 3: How are GPS data used to develop hazard maps? What can be done to lessen the severity of earthquake impacts? How do careers in computational geoscience play a role in the lives of everyday citizens? Students will consider community resiliency. They will assemble code to create a map showing the build-up of land deformation using GPS data near Stockton (Figure 4). Students will then interpret the map with respect to the likelihood of an earthquake occurring and population distribution. Students will then connect the analysis to the community asset map they created in the first unit. Students will study what geoscientists communicate in terms of earthquake warning, preparedness, and mitigation and assess their neighborhood buildings' readiness for earthquakes. Students will then compare computational geoscience practices they have been doing in the *YouthQuake* curriculum with what geoscience professionals actually do in their efforts to make earthquakes impacts less severe. Students will talk to undergraduate students pursuing careers in computational geoscience to learn about their experiences working in the field. They will also connect their investigations to professional work in the field through videos created by UNAVCO that feature a diverse group of professionals working at all levels. Finally, students will brainstorm ideas about what might reduce the severity of impacts in their community.

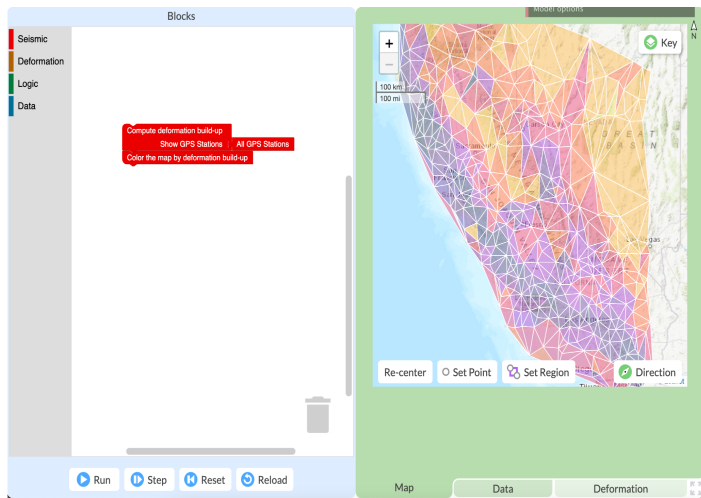

Figure 2. The GeoCoder displaying deformation build-up near Stockton.

Student summative independent project. In small groups, students will develop a "Public Service Announcement" for their communities. Students bring together their knowledge from the three units about the likelihood of a major earthquake in their neighborhood, information about the community's assets, and suggestions for how to prepare for an earthquake. Students will be challenged to think about how to reconcile the language of science with that of their communities to best communicate the information about earthquake hazards and risk.

Project Research

Two cycles of design-based research will be carried out to iteratively revise and refine the *YouthQuake* curriculum and equity-promoting strategies. Design research requires systematic data collection and analysis based on established learning theories, available research results, and our prior research and development experiences. Through this process, we will refine the materials as well as the underlying theories used to develop them. We will use a mixed-methods approach with tests, surveys, embedded assessments, and videos to answer the questions below.

Research Questions (RQs)

RQ1. What do students learn when engaging in the computational geoscience practices while learning about earthquake hazards and risk? How do Hispanic and African American students associate their participation in the practices with community relevance, personal meaning, and computational geoscience identities and careers?

RQ2. What aspects of the computational geoscience practices enhance or impede the Hispanic and African American students' legitimate participation in social, epistemic, and material (i.e., use of tools) dimensions of the practices?

RQ3. How and to what extent are equity strategies reflected in the design of the curriculum enacted in the classroom to support Hispanic and African American students' engagement with the practices?

Year 1: Design Cycle 1

During the first year, we will conduct one design cycle. In the summer of 2023, the partners will convene in a four-day workshop to review and reconfigure the seismic module from the *GeoCode* project. The original 5-day module focused mainly on the computational treatment of earthquake hazards and risk assessment by (1) domain knowledge (earthquakes in California occur because of land deformation caused by the plate movements), (2) data visualization practice (tracking land movement), and (3) computational modeling practice related to earthquake risk based on land deformation. The partners will create blueprints for three units contextualized in the Stockton community with research-based equity strategies known to be successful in engaging Hispanic and African American students. The partners will review the instruments for assessing students' computational reasoning and computational geoscience identities and career choices. The first version of the expanded *YouthQuake* curriculum will be finalized in the fall of 2023. Four teachers from the middle schools in Stockton, who participate in the partner workshop, will implement the *YouthQuake* curriculum (student n = 320, 80 students per teacher). Teachers will also implement pre- and post-tests related to computational geoscience reasoning, identity, and career interests along with student demographic surveys. The research team will be present in two teachers classrooms to troubleshoot technology, make observations, collect videos of the whole class as well as two student pairs per class, and debrief equity strategies at the end of the implementation.

Year 2: Design Cycle 2

Year 2 will start with a four-day partners workshop in the summer. Partners will review preliminary analysis results including students' computational geoscience practices captured in the student work and the videos as well as pre-/post-test changes in computational reasoning and computational geoscience identities. Using the videos collected in Year 1, research will examine equity strategies enacted by the teachers. In the fall of 2024, the partners then revise the *YouthQuake* curriculum and will identify the equity strategies that were most effective for engaging Hispanic and African American students. The project will offer three-days of professional development for six new teachers from the Stockton middle schools (n=800 students) prior to the implementation of the revised curriculum. The ***professional development (PD) workshops*** will be held at the FabLab and focus on 1) science content and coding foundational to the curriculum, 2) equity strategies and sense-making that are interwoven into the curriculum, 3) the project's research goals including broadening awareness of computational geoscience careers. In doing so, the PD will help teachers connect *YouthQuake* content and investigations to students' lived experience while leveraging and supporting students' ideas and resources as the class works to build scientific understanding about earthquake risk and preparedness [93]–[96]. Ten teachers (6 from the workshop plus 4 partner teachers from Year 1) will enact the curriculum. We will collect the same data as in Design Cycle 1.

Year 3: Establishing Evidence-based Knowledge

In the last half-year of the project, we will analyze the Year 2 data and iterate theories that explain Hispanic and African American students' learning of the computational geoscience practices featured in the *YouthQuake* curriculum and the changes in computational geoscience identities and career interests. We will hold three one-day online partner workshops in the summer following the second design cycle to share analysis results in light of our research questions. Partners will provide their own expertise and viewpoints to evaluate results and contribute to the interpretation of the results. The project evaluator will moderate and synthesize the different perspectives. The partnership will also discuss the viability, applicability, and sustainability of equity strategies enacted with the *YouthQuake* curriculum to determine which strategies are specific to the project and which are transferable to the teaching of other science topics. The findings will be written and disseminated.

Data Collection and Analysis

To answer RQ1, we will administer a computational geoscience reasoning instrument to students before and after the *YouthQuake* curriculum in order to investigate what students learn from the curriculum. We will also administer computational geoscience identity and career instruments before and after the curriculum. We will collect students' demographic information before the curriculum implementation and their evaluation of the computational geoscience experience in terms of community relevance and personal meaning after the curriculum implementation. For RQ2, we will use student work generated during the curriculum and videos of the whole class and student pairs to determine Hispanic and African American students' participation in the social, epistemic, and material (resources and tools) dimensions of the computational geoscience practices. RQ3 will be answered by the partnership through the synthesis of results from all data sources including pre/post-test results, pre/post computational geoscience identity and career choice responses, student work in the curriculum using embedded assessments, videos, and classroom observations. Data sources and analyses are listed below.

Pre/post computational geoscience reasoning (CGR) instrument associated with earthquake hazards and risk. We developed and tested a version of the CGR instrument in the *GeoCode* project. The instrument consisted of 18 multiple-choice and 8 open-ended items and addressed a series of investigation steps professional computational geoscientists need to follow when they use GPS data to measure land movement, visualize land movement and deformation, and forecast earthquake hazards and risk. The CGR instrument showed an inter-item reliability of 0.81 Cronbach alpha and had a single dominant factor with an eigenvalue of 4.82, while all other factors' eigenvalues were below 2.0, indicating the presence of an underlying construct. As the materials are expanded in the *YouthQuake* curriculum, we will update the CGR instrument by situating the items in the community-specific contexts and adding items related to surveying local risk and community assets (Unit 1) and mitigation and communication strategies for the local community (Unit 3 and summative project). In the first design cycle, we will administer the updated CGR instrument as a pre-test and post-test to 320 students of four teachers. We will revise the CGR instrument and administer it as pre-test and post-test to 800 students of 10 teachers in the second design cycle.

To establish the construct validity with the revised CGR instrument, we will use the construct modeling approach in four steps [97]: (1) a construct map is theorized from the relevant literature on the target construct; (2) items that elicit various levels on the construct map are selected for an instrument; (3) student responses are collected on the instrument; and (4) appropriate item response models are applied to student response data. We will use Rasch Modeling of student responses to establish the validity of each instrument [98], [99]. To ensure Rasch Modeling is appropriate, we will test for multi-dimensionality with exploratory factor analysis (EFA) using principal axis factoring with a promax rotation [100] and Q3 statistics for local independence testing [101]. With the students' responses to the pre-test and the post-test, we will first compare student performances at each item level using repeated measures Wilcoxon signed rank tests to examine whether students improved on a particular CGR item across teachers as well as ethnic and racial groups, in particular for Hispanic and African American students. As we anticipate students' computational geoscience experience will be differently shaped by the teacher, this analysis will allow us to examine which aspects of computational geoscience reasoning are significantly improved and which are not. We will use this information to interpret whether or not equity strategies we observed in the classroom had an impact on students of various ethnic groups. We will also create a student learning outcome variable with the student ability estimates from the Rasch analysis and apply repeated measures ANCOVA with the teacher as a fixed effect and other student demographic variables (e.g., gender, prior computer usage for science learning, language, and ethnicity) as covariates. This repeated measures ANCOVA analysis will allow us to examine how variations in teacher enactment of the curriculum impact student learning, as well as for whom the *YouthQuake* curriculum is beneficial.

Pre/post computational geoscience identity and career interest instrument. Middle school years are considered critical for formulating career aspirations [102] and coincide with the declining interests in science and engineering disciplines [103]. We will use the ISME (Is Science Me?) survey [104], [105], which was developed to investigate students' STEM career development from the perspective of social practice theory [17]. The ISME survey includes 10 science self-perceptions items (Cronbach alpha = 0.82) in a four-point Likert scale response format (strongly agree, agree, disagree, and strongly disagree) and career interests items related to science, engineering, technology, and medicine [60]. Kang et al. [93] modified the self-perceptions items to create the self-perceptions in and with science construct (alpha = 0.82) and about science and scientists' work (alpha = 0.81) to represent STEM identities. Science career items ask, "How interested are you in having a job like… some day?" Since these items were developed for science in general, we will modify them to address how the computational geoscience practices are carried out for forecasting earthquake risk. To validate the computational geoscience identity items, we will conduct the principal components factor analyses based on varimax rotation techniques [106]. We will test (1) whether students significantly improve on their computational geoscience identity before and after the *YouthQuake* curriculum using repeated measures ANOVA with gender, race, language, and prior use of computers for science learning covariates, and (2) whether significantly more students choose computational geoscience careers using chi-square. In addition, we will carry out a mixed effects repeated measures logistic regression analysis on the probability of students' computational geoscience career choice with gender, race, language, and prior use of computers for science learning, and the post *YouthQuake* computational geoscience identity as fixed effects and teacher as a random effect.

Student and class videos capturing computational geoscience practices in action. In order to capture how the teacher enacts the units and how students carry out computational reasoning, we will collect whole class videos, and student pair videos. In the first design cycle, we will work with two of the partner teachers to collect whole class video as well as videos of student pairs (two pairs per class per teacher). These student videos include voices and computer screens capturing student interactions with one another, as well as with the curriculum. In selecting student groups, we will consider grouping of Hispanic and African American students based on science achievement determined by pre-test scores and in consultation with the teachers. In the second design cycle, we will collect the whole class videos and student pair videos from four teachers' classes (two from design cycle one and two new teachers). There will be 12 student pairs chosen for video data collection (3 student pairs x 4 teachers). We will investigate how teachers and students negotiate epistemic agency when learning about earthquake hazards and risk. The analytic foci will adopt Stroupe [20]'s framework used to investigate how students participate in social, epistemic, and material dimensions of the computational geoscience practices.

- Who elicits social, personal, community, scientific, and computational ideas?
- Who makes decisions on which ideas are important to further pursue or ignore?
- On what grounds are value judgments and decisions made in the classroom?
- How do these value judgments and decisions influence ways in which students engage in computational geoscience practices and how they communicate in the classroom community?

Student work related to the computational geoscience practices in the curriculum. The *YouthQuake* curriculum's embedded assessments will elicit students' responses, including 1) multiple-choice answers, 2) written descriptions or explanations, 3) code used to create computational visualizations, 4) drawing predictions, and 5) evidence-based scientific arguments. Students' responses to embedded assessments will be recorded automatically by the server and will be retrieved later and analyzed to investigate the extent to which students engage with geoscientific and computational reasoning.

Expertise and Management

Amy Pallant will serve as Principal Investigator. She will direct the development of the *YouthQuake* curriculum and technology and will be responsible for the overall coordination of the partners, the enactment, and budgeting of the project.

Hee-Sun Lee, Ph.D., **(**Co-PI) will coordinate and carry out research on student engagement of and identity with computational geoscience practices and construct and validate assessment instruments.

Jie Chao, Ph.D., (Co-PI) will coordinate the creation of new features in GeoCoder and analyze student learning process data to understand how students reason about risk and preparedness.

Donna Charlevoix, Ph.D., (Co-PI) will supervise project activities at UNAVCO, ensure that the necessary UNAVCO resources and support are available, and assist with the education research.

Stephen Callahan, (co-PI) is the educational technology coordinator at the San Joaquin County Office of Education FabLab. He will be responsible for professional development and assisting teachers.
Shelley Olds, science education specialist at UNAVCO, will help develop materials and provide necessary GPS data and will serve as a liaison to the USGS *ShakeAlert* project.

Anika Knight is a geoscientist and the workforce and diversity specialist at UNAVCO. She will bring her experience and coordinate guest speakers.

Rocco Malversis, Ph.D., and **Charles Connor**, Ph.D., will serve as computational geoscience consultants and partners and will provide expertise on computer modeling and data analysis related to seismic and volcanic hazards.

An **Advisory Board** will provide 1) expertise concerning project operation and implementation (materials, instruments, and protocol development; data collection and analysis; and research findings) and 2) insights on how the research efforts, findings, and tools may be refined. The Advisory Board will meet face-to-face in the first year and will meet with staff via Zoom throughout the project and for an online meeting in the second year. **Dr. Jose Rios** is an associate professor of teacher education at the University of Washington Tacoma. His research focuses on examining diversity and equity in STEM teacher preparation. **Dr. David Stroupe** is an associate professor of teacher and science education at Michigan State University. His research interests are anchored around ambitious and equitable science teaching. **Dr. Hosun Kang** is an associate professor in science education at the University of California, Irvine. She studies how to reduce the opportunity gap of science learning for students from historically marginalized communities. **Marcus Sherman** is the K12 Science Curriculum specialist for the Stockton Unified School district and has recruited ten teachers to participate in *YouthQuake*. **Dr. Charles Connor,** is a co-PI on the *GeoCode* project and is a professor in the school of geoscience at the University of South Florida, specializing in computational modeling of hazards caused by tectonic plate movements.

Project Evaluation

The evaluation will focus on the partner meetings, the development of the curriculum, and the research process along with equity and broadening participation strategies. The evaluation will be led by **Dr. Orrin Murray**, a principal researcher and learning scientist specializing in equity and culturally responsive practices in schools at American Institutes for Research (AIR). By providing external oversight throughout the project, the evaluation will support staff in tracking progress. The evaluator will be present in partner meetings and collect data about ongoing work, including educational program reviews, meeting observations, and discussions with partners. In collaboration with project staff, these data will be compared against the project's proposed goals, timelines, instrumentation, and analytic strategies so that ongoing activities and deadlines can be realigned with the intended plans and/or intended plans can be adjusted to thoughtfully account for the realities of project work. The evaluation of the equity strategies will focus on student engagement. Students who report high levels of epistemic engagement with the *YouthQuake* curriculum in classrooms will exhibit more sophisticated computational reasoning and higher computational geoscience identities than those who do not. This relationship has been shown to be especially important for Hispanic and African American students [107], [108]. To investigate epistemic engagement, the evaluation will focus on whether and to what extent the curriculum activities are culturally responsive and personally meaningful and how teachers make connections between what they learn about the lives of their students and how this lived experience can support the building of a classroom culture that is inclusive, content rich, relevant, and academically rigorous. In addition to observations of classrooms, Dr. Murray will use the PERTS Elevate instrument [109] to reflect back on students' perceptions of belonging and relevance in their lives.

Dissemination

All materials created for this project will be available in electronic forms on the Concord Consortium and UNAVCO websites. The materials will also be shared with districts in California where this program is most applicable. The partners will work together to promote project materials and research findings. The partners will present at conferences (e.g., National Science Teaching Association, California Science Teachers Association, National Association of Research in Science Teaching, and International Society of the Learning Sciences) and publish articles in peer-reviewed journals (*Journal of Research in Science Teaching, International Journal of Science Education, Science Education,* and *Journal of Geoscience Education, Journal of the Learning Sciences, Science Scope and The Earth Scientist*). The partners will support dissemination of ideas related to knowledge, equity, career awareness, and natural hazards safety and preparedness. This includes writing and speaking to different audiences such as school decision makers, policy makers, parents, and other community members and take the form of blog posts, video (YouTube, TikTok), and infographics. Finally, we will disseminate the work through social media and the *@Concord* biannual newsletter, distributed for free to over 63,000 subscribers.

Intellectual Merit

This project will investigate how authentic, community-specific, real-world investigations can support urban Hispanic and African American students to engage in computational geoscience practices, leading to the development of computational geoscience identities and career interests. Several equity strategies will be investigated: (1) using contextual scaffolds to help students bridge real-world problems with their diverse forms of science knowledge and experiences, (2) engaging students in authentic investigations and practices of career professionals, (3) building on students cultural assets and strengths derived by belonging to different communities, and (4) empowering students to become epistemic agents in shaping their knowledge and practice. The project will produce evidence-based knowledge and an exemplar student technology experience that addresses these equity strategies. These can be further used by other researchers and developers to create in-school science experiences that support Hispanic and African American students' career aspirations towards computational geoscience.

Broader Impacts

The work will be carried out by an interdisciplinary team from the Concord Consortium, UNAVCO, , the San Joaquin County Office of Education FabLab, consultants from University of South Florida and middle school teachers from Stockton, CA. The project will directly impact 10 middle school teachers and approximately 1,120 middle school students during the project period. The project will actively share materials and experiences with other teachers through the California Science Teacher Association annual conference, webinars, and resources. Through our partners and advisors, we will support the training and use of the curriculum and assessment instruments by other middle school teachers in San Joaquin County after the conclusion of the project. In addition, other researchers and developers will have access to any of the materials for free. Findings from research will be disseminated through academic and practitioner journals, conferences as well as newsletters, blog posts, and social media.