Using Block Coding to model GPS motion, land deformation, and earthquake risk

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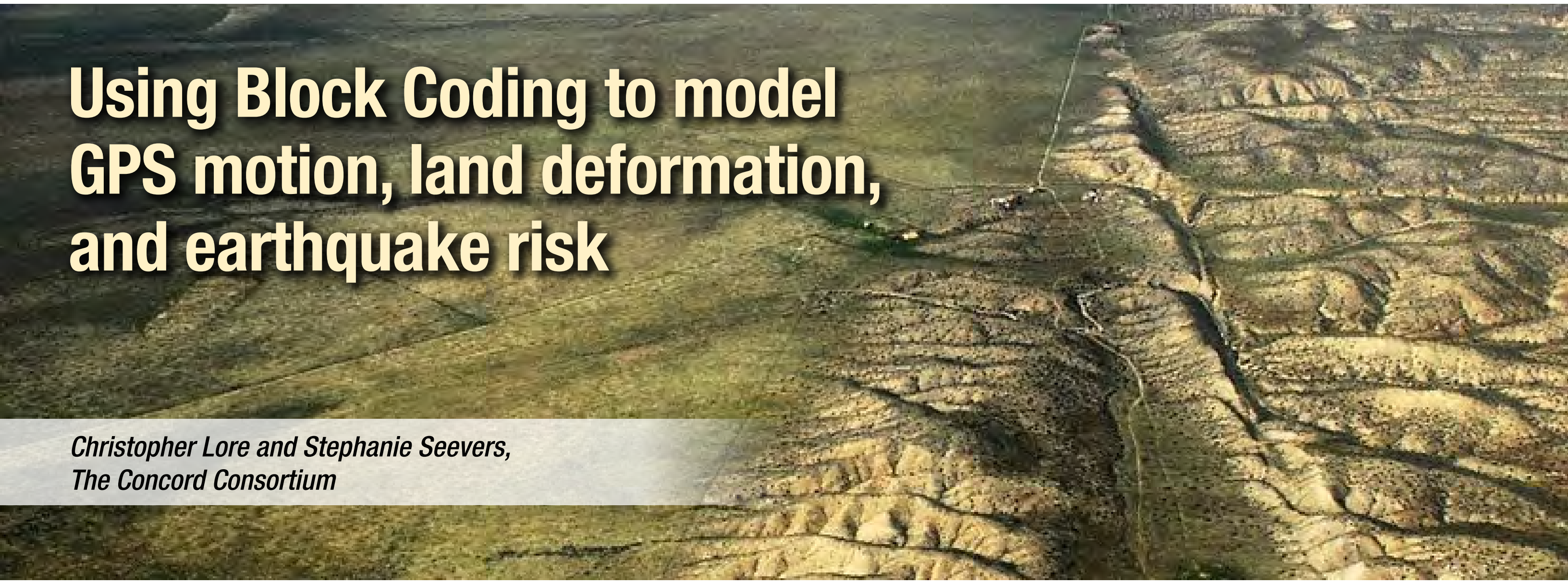

Deep underground forces explain earthquakes along San Andreas Fault
Photo Credit: Wikimedia Commons

Abstract

Computation is quickly becoming an essential part of science investigations. Especially in the geosciences, where enormous datasets are collected throughout the investigation of Earth-scale processes, scientists turn to computation to help them filter, analyze, and visualize the data. This fact is reflected in the Next Generation Science Standards, which include “using computational thinking” as a key science practice. The GeoCode project’s curriculum module “Assessing Seismic Hazards and Risk with Code” integrates science practices with computational thinking. In this module, students produce data visualizations of GPS movement in California, create code to investigate how land movement causes earthquakes, and synthesize different datasets to assess how deformation build-up poses risks to people and their communities. Through interactions with the GeoCoder model, students build block codes to investigate GPS velocities, the earthquake cycle, and how the rate of land deformation correlates to seismic hazard and risk. Results from classroom implementations indicate students made significant learning gains and recognized the value of coding in helping them understand the complex earthquake cycle system. In addition, teachers reported high student engagement and interaction with the materials.

Introduction

For many middle and high school science teachers, the idea of computer coding in an Earth science class might sound far-fetched. These two disciplines are traditionally separated into not only discrete classes, but also completely different departments. However, today’s Earth scientists and geoscientists routinely use computational models in their work. It’s time to introduce coding as a necessary and accessible practice for Earth science students, too.

The three-dimensional learning model espoused by the Next Generation Science Standards is a vision for teaching science not just as a body of knowledge, but also as a process for acquiring and refining knowledge (NGSS Lead States, 2013). Students in K-12 science classrooms are expected to learn the *practices* of real scientists but doing so in Earth and space sciences can be challenging. The processes and structures involved in the study of the Earth are too large, both physically and temporally, to fit into a classroom (Pallant et al., 2020).

For example, consider the study of latent heat in the Earth's energy budget or its impact on weather and climate patterns. Chemistry students can set up an experiment with ice, a hot plate, a thermometer, and a calorimeter to investigate phase change and the latent heat of water, and by the end of a single lab period, they will have all the data they need to draw a graph and construct explanations about the phenomenon. In an Earth science classroom, on the other hand, students would want to explore the far-reaching and interconnected effects that latent heat absorption and release have on the atmosphere and oceans. A real-world investigation into this would require enormous datasets, collected over many years, across hundreds or even thousands of miles, and are best analyzed via computer. Fortunately, abundant computer-based simulations and models, virtual labs, and online access to real-world datasets are now available to middle and high school teachers and students.

The goal of the National Science Foundation-funded *Visualizing Geohazards and Risk with Code (GeoCode)* project is to integrate scientific and computational practices in the study of volcanic eruptions and earthquakes, using large, real-world datasets. The project developed a weeklong module for middle and high school students that integrates Earth science content with computational thinking practices while engaging students in an authentic geoscience problem. More information about the GeoCode project can be found at learn.concord.org/geocode-seismic.

In "Assessing Seismic Hazards and Risk with Code" students use GPS position data from across California as evidence of crustal deformation along the San Andreas Fault Zone to answer the driving question: Who in California is at risk from an earthquake? Although raw GPS data is difficult to interpret, by transforming it into visualizations, students can see the emergence of patterns in the speed of the land's movement and its direction. By modifying the inputs into a model, students learn about the factors that are important to explore. Further, coding the visualizations themselves allows students to see the importance of computation for authentic investigations.

Because California is one of the most active seismic areas in the United States, the region's seismicity is monitored by many organizations. Project partners at UNAVCO manage the data from the GPS stations. We worked closely with UNAVCO scientists and with seismologists at the University of South Florida to design the curriculum and model the ways they conduct research and computational modeling.

The GeoCoder

The module incorporates a block-based programming tool called GeoCoder, consisting of a programming workspace and a map visualization (Figure 1). The GeoCoder is designed so that every block in the program workspace on the left produces a visual output on the right. The outputs include easy-to-interpret data visualizations and land deformation models, similar to representations used by scientists. The module scaffolds students as they learn to program simulations, create and interpret data visualizations, and consider the likelihood of hazards. With this design, students have the ability to:

- Run simulations easily with multiple inputs
- Create code to control output visualizations
- Create scientific visualizations of large datasets
- Analyze data and models in order to develop scientific explanations
- Design experiments to answer scientific questions

Students learn how scientists collect data using GPS technology, use the data to explore and model plate motion, create hazard maps, and make forecasts about future hazards. They also learn how coding enables them to make sense of otherwise inaccessible content in the same way scientists do.

Data Visualization with Code

Students begin their investigation of seismic hazards and risk by exploring the network of GPS stations in California and the data provided by the network. Using a set of several hundred active GPS stations, students are prompted to find patterns in the speed and direction of the land in California. Which direction is the land moving? How fast is it moving? Are all places moving at the same speed?

Each GPS station has a record of its own attributes, such as its current latitude and longitude, speed (in millimeters per year), direction of movement, and date it was added to the network. Several stations in the GeoCoder also have a record of their daily position data starting from the day they were installed to the day they were downloaded to the GeoCoder software. By using code blocks to define a specific station and the time range of data they want to see, students can visualize the daily position of that station over time and, therefore, the movement of the land it is bolted to (Figure 2). The ability to quickly and efficiently manipulate this large dataset allows students to become scientists themselves, comparing multiple plots of thousands of real data points in order to identify trends and draw conclusions about the velocity of GPS stations in California.

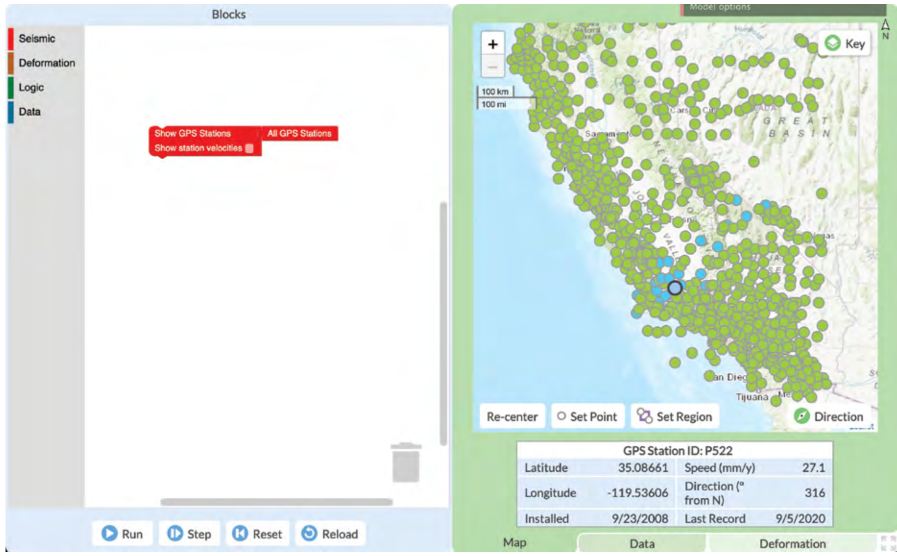

Figure 1. The GeoCoder model uses block code to visualize all of the GPS stations on the map of California. Green stations indicate GPS stations. Stations in blue include a complete history of daily position data. When a station is selected (the circle with the black outline), the information for that station is displayed below the map.

Photo credit: geocode-app.concord.org/branch/master/index.html?unit=Seismic

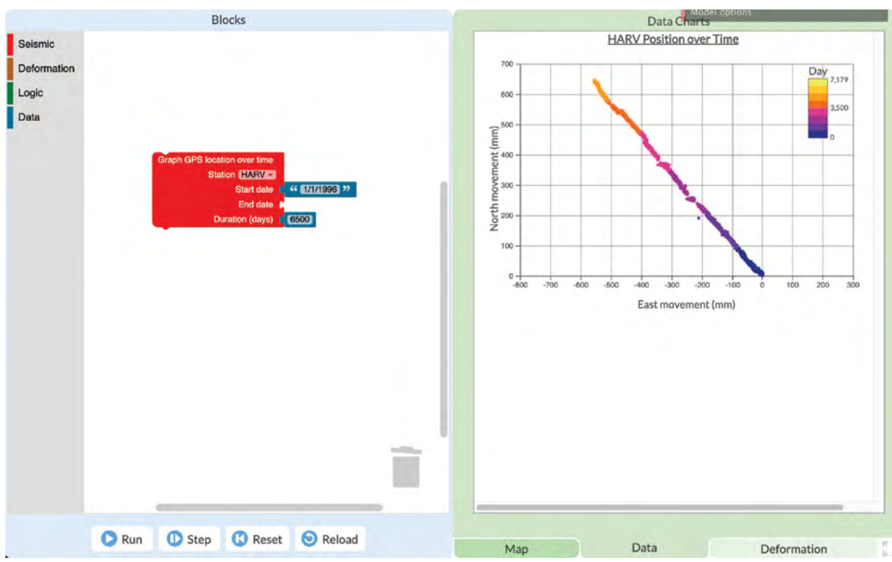

Figure 2. The GeoCoder model has access to the daily position data for several GPS stations. Students can plot data from multiple stations and compare their movement over time.

Photo credit: geocode-app.concord.org/branch/master/index.html?unit=Seismic

Coding Deformation Models

After investigating real-world GPS movement, students explore how different rates of land motion are related to the occurrence and frequency of earthquakes. Students use the Deformation Simulation in the GeoCoder to simulate the movement of two tectonic plates and the deformation of the land on those plates (Figure 3). Using block code, students can set the speed of the two plates, the friction level between the plates, and the amount of time, in simulated years, to run the simulation. To try out the GeoCoder yourself and build your own code, visit https://geocode-app.concord.org/branch/master/index.html?unit=Seismic.

The wording of the code blocks, or syntax, helps students bridge the gap between the science concept they are investigating and the computational processes they need to carry out in order to use the visualization to ultimately answer the driving question. For example, the conditional statement at the bottom of the code in Figure 3 uses scientific terms to describe what is going to happen in the visualization when students run the code. In regular language, the code says, “If the amount of deformation in the model is greater than the maximum amount of deformation the plates can undergo, as determined by the friction level [set by students], then an earthquake will occur in the Deformation Simulation. If not, loop back to the beginning and run through another year of simulated plate movement."

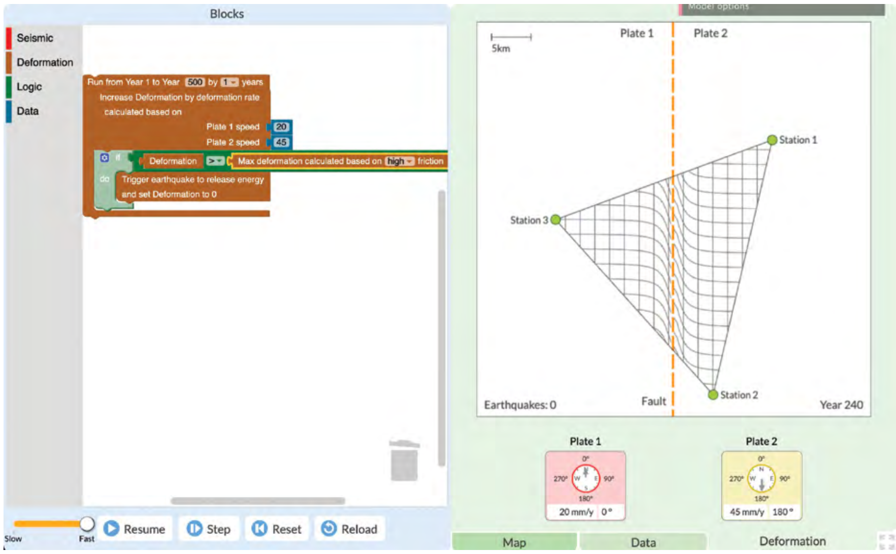

Figure 3. The Deformation Simulation (right) and associated code blocks (left). This visualization helps students understand land deformation along a fault based on the movement of the land and the friction level between the two sides of the fault.

Photo credit: https://geocode-app.concord.org/branch/master/index.html?unit=Seismic

A key concept in computational thinking is being able to translate a scientific investigation into code, and the descriptive code blocks lower that barrier. The GeoCoder design is intended to help students gain a deeper understanding of the earthquake cycle and why earthquakes occur while they also learn about common coding features such as loops and conditional statements.

In addition, the Deformation Simulation helps students build a mental model of how the surface of the Earth reacts to the plate movement they set in the code. As the simulation runs, the grid lines on the two plates bend and squish according to real mathematical models of deformation around a transform fault. When an earthquake occurs, once-connected grid lines snap apart and back to straight, representing the elastic deformation of a brittle surface land. Immediately after an earthquake, land deformation begins to build up again, and the earthquake cycle continues. Students use the simulation to help explain why many places in California experience earthquakes every few years—and why scientists know "The Big One" is coming.

Student Experience

The "Assessing Seismic Hazards and Risks with Code" module was piloted at a mountain community Colorado high school first in April 2020, again in December 2020, and most recently with 87 ninth grade students in three Honors Earth science classes in December 2021. While all students began with similar prior content knowledge of plate tectonics, they had varying amounts of coding experience. Some students carefully followed the tutorials to write their first lines of code, while others were able to jump ahead to use functions before they were introduced.

In focus group interviews after completing the module, students generally agreed that the block coding became easier as they stepped through the activities and gained coding practice. One student remarked that using the code blocks to change the parameters of the model allowed her to understand the resulting changes in the visualization more easily. In particular, adjusting the inputs to the Deformation Simulation helped her to comprehend the relationships between friction, deformation build-up, and earthquake frequency in a way that had eluded her during a previous lab using physical models.

Pre- and post-test performance showed that students made significant gains in their understanding of plate motion, deformation, and seismic risk. On a teacher-created pre-test, the mean score for all 87 students was 21%. The post-test mean score was 76%. The largest gains were in students' ability to represent graphically the cycle of deformation and release along a fault. Significant gains were also made in students' abilities to discuss factors that affect seismic risk for a location. [The GeoCode: Seismic project's official pre- and post-tests can be found at learn.concord.org/geocode-seismic. You must have a teacher account (it is free) and be logged-in to view and assign these activities.]

Teacher Feedback

The four Earth science teachers at the pilot school have found GeoCode to be a valuable way to involve students in real-world investigations of hazards and risk. They have made it a permanent part of the ninth-grade science curriculum and plan to use two GeoCode modules with students every year. (In addition to “Assessing Seismic Hazards and Risks with Code,” GeoCode developed another module called “Assessing Volcanic Hazards and Risks with Code.”)

The first year of the GeoCode implementation was at the beginning of the pandemic, and instruction was completely asynchronous online. Even without any face-to-face contact, students were able to complete the activities with a sufficient level of understanding. The 2020-2021 school year brought a hybrid in-person/online setting, and the pilot teachers reported that their students fared better with that increased access to teacher help. Finally, the December 2021 implementation was in a regular classroom setting, and students thrived through the ability to work with their classmates and have teacher guidance daily. While the module is robust enough to be used by students independently, the pilot teachers agree that it is most effective when used with a teacher to facilitate the lessons.

According to the teachers who implemented the pilot, the greatest advantage of the GeoCode module was the use of large, real-world datasets. Giving students the opportunity to analyze and visualize these datasets allows them to participate in authentic geoscience practices in the classroom. Coding helps students change different variables in the visualization of the data deliberately and systematically and see the changes in the outcomes immediately, thus helping them to better understand cause and effect relationships in a complex system. By integrating computer coding into Earth science content, the GeoCode module offers problem-solving opportunities to students not only in science, but with writing code as well. Students can engage in three-dimensional learning in the Earth science classroom.

The GeoCode: Seismic curriculum and assessments can be accessed for free at learn.concord.org/geocode-seismic.

References

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About the Authors

Christopher Lore began working at The Concord Consortium three years ago after receiving a B.S. and M.S. in geology from Rensselaer Polytechnic Institute. At The Concord Consortium, Christopher has worked to build earth systems models that allow students to explore complex, interacting systems that are too big to see in a lab. Christopher can be reached at clore@concord.org

After earning a degree in geology at UC Santa Barbara, **Stephanie Seevers** worked in petroleum and environmental consulting before beginning to teach high school science in 1998. This year, she is teaching part time while also working with The Concord Consortium as a teacher consultant on several projects aimed at bringing real-world data and better models into Earth science classrooms. Stephanie can be reached at sseevers@jeffcoschools.us