

Separating the Signal from the Noise: Promoting Alaskan students' inquiry with geographically relevant seismic data and machine learning techniques

This three-year medium size project in the PreK-8 strand leverages a research-practice partnership to develop Alaskan middle school students' computer science (CS) and machine learning (ML) skills and practices via block-based programming within an online curriculum focused on scientific inquiry of real-world seismic waves.

Importance

The Earth's crust is constantly vibrating from natural and human-caused tremors. Situated close to the edge of the North American tectonic plate, Alaska experiences thousands of earthquakes annually [1]. Here, at this convergent plate boundary, the Pacific Plate subducts under the North American plate. The mountains resulting from the collision of plates also produce rock slides and avalanches, which send vibrations through the upper portion of Earth's crust. Furthermore, due to Alaska's extensive coastline, the ebb and flow of tides and the crashing of waves against the land cause further vibrations. Humans, too, cause noticeable movement on Earth's surface. Construction sites, roadway traffic, sporting events, and many other activities all cause small vibrations. These vibrations of Earth's crust, called seismic waves, are measured and studied by seismologists using accelerometer sensors.

New machine learning (ML) techniques have transformed the field of seismology. Machine learning is a branch of artificial intelligence (AI) designed to identify patterns and relationships embedded in large datasets. In the past, seismologists used a sequence of manual processing steps to monitor seismic activity, including hand labeling seismograms to decipher seismic events and their sources. With modern computational methods, scientists can now train an ML model to efficiently and accurately process, filter, and analyze seismic signals. Seismologists now rely on ML to conduct real-time identification and classification of seismic data constantly being collected by thousands of networks seismographs around the globe [2]. They then use these data to extract information from seismic waves and gain new insights [3]. For instance, was the tremor from a sports event, construction, roadway traffic, or a potentially dangerous earthquake? Based on the ability to identify features nearly instantaneously, ML is capable of making these distinctions.

Seismology provides an ideal context in which to engage students in learning Earth science and computer science (CS). The Next Generation Science Standards [4] states that students should analyze and interpret data on natural hazards to consider their potential impact, mitigate their effects, and use scientific evidence to build understanding. Additionally, it is essential for students to learn disciplinary core ideas through science practices that authentically reflect the ways in which scientists conduct their research [5]. However, authentic geoscience is typically not accessible to students in the way it is practiced by seismologists [6], [7] because it is not trivial to translate geoscientists' resources, methods, and tools into materials that are appropriate for engaging students in inquiry-based activities [8]. Authentic computational practices used in seismology such as combining hardware and software, programming, problem solving, and creating data visualizations need to be simplified, but not distorted, to a level appropriate to students. The progression of the field of seismology towards CS- and ML-based research methods creates a transformative research opportunity to design and research CS- and ML-supported geoscientific inquiry investigations for students.

Integrating CS and ML into science classes allows all students to gain access to these essential skills and practices. In 2018, the Alaska State Board of Education and Early Development identified CS as a foundational skill that all students will need for their futures [9]. They recognized that "whether the students grow to pursue computer-related careers, CS education...prepares Alaska students for the 21st century work force" [9]. Additionally, the State has committed to furthering teacher professional learning in CS, including CS preparation for teachers interested in integrating CS in their subject areas [9].

Project Goals and Objectives

The *Separating the Signal from the Noise* project (SeismicML for short) **will engage Alaskan middle school students in contextualized inquiry investigations with local seismic data to help them understand authentic applications of CS and ML in modern science.** We will develop a pedagogical model for integrating CS and ML practices with investigations central to the work of modern seismologists. To accomplish this, this RPP brings together expertise from the Concord Consortium (CC) in technology and curriculum development, a geophysicist from the University of Washington (UW) with expertise in applying ML to large seismic datasets, a science education researcher and teacher professional development provider from Kent State University (KSU), and teachers and administrators from the Anchorage School District (ASD) with experience in implementing innovative, technology-focused curriculum. We will address the need for computationally integrated science materials that engage Alaskan students in an engaging curriculum that meets state CS standards. The project will meet this goal through a set of targeted objectives:

Objective 1: Develop and study prototype software and instructional materials for middle school students that integrate CS and ML learning with geoscience content around earthquakes. The SeismicML project will create a block-based programming workspace where students use CS and ML practices to collect, filter, identify, and classify seismic wave data collected by Raspberry Shake seismometers in their classrooms. We will translate an existing scientific-grade ML model that can computationally identify a variety of seismic signals from the ubiquitous background vibrations of Earth. We will also develop an online, inquiry-based curriculum module that will scaffold students to use the ML model to investigate real-world seismic wave data in their local area.

Objective 2: Understand the novel affordances of integrating local seismic data, geoscience content, and authentic CS and ML practices for engaging students in seismic investigations. Students will construct, iterate, and interpret block programs and computational visualizations to explain seismic phenomena. We will study how students use and refine ML models to make them more accurate to real-world seismic events and how they make sense of the computational outputs of the programs they create. Our approach will leverage access to vast amounts of seismic data through an extensive seismograph network to improve teaching and learning of Earth science by integrating key science concepts with computational practices. Through this work, we aim to develop middle school students' scientific inquiry through the deliberate synergistic interweaving of both disciplines and their practices through investigations of real-world seismic signals.

Objective 3: Conduct research on students' CS and ML learning, science knowledge, CS attitudes, and perceived relevance. Through a Design-Based Implementation Research (DBIR) study [10], [11], we will investigate the supports necessary to fully engage teachers and students in successfully implementing the curriculum module. The project will investigate the benefits of integrating computational practices in science classrooms on students' attitudes, perceived relevance of instruction, and content knowledge. The project will contrast student outcomes associated with module use within teachers while diminishing confounding variables such as teaching style, personality, and experience. Through the collection of student answers to questions embedded in the curriculum, snapshots of block programs, surveys, interviews with teachers, and recordings of classroom discourse, the project team will work to investigate the jointly developed research questions below.

RQ1. (*Improving understanding through computationally integrated science investigations*) How do students translate their understanding of seismic waves into an algorithmic model to investigate and classify the sources of seismic signals? To what extent does using the computationally integrated seismic curriculum build students' computational practices and geoscience content knowledge?

RQ2. (*Curricular impact on student learning*) What are the novel affordances of integrating geographically relevant data, geoscientific concepts, and authentic CS and ML practices for engaging middle school students in meaningful seismic investigations? Is student engagement with an authentic computationally integrated Earth science curriculum associated with improved attitudes, perceived relevance, and science learning outcomes?

RQ3. (*Supporting teachers in teaching with integrated CS and science materials*) What types of teacher, curricular, and computation-related supports are necessary to engage students in computationally integrated seismic investigations? In what ways do teachers use their everyday experiences to inform their teaching with locally relevant materials?

Design Principles for the SeismicML Instructional Materials

SeismicML will apply the following design principles when developing the module.

Translating authentic computational seismic wave investigations for use in middle school classrooms. The NGSS calls for the translation of scientists' resources and tools to accommodate students' inquiry-based activities. The field of seismology, which studies the propagation of seismic waves through the Earth, provides a rich context for authentic CS inquiry activities because the field has increasingly relied on computation to conduct research [12]. Using computational methods in seismology is necessary due to the huge datasets and dispersed network of connected sensors used in the identification and classification of seismic waves. The process of collecting, analyzing, and visualizing data using a programming tool comprises several of the CS practices defined by the Alaska Computer Science Standards (ACSS) [13]. To make such authentic science practices available to students, scientists' activities should be translated by simplifying scientific terms, reducing unnecessary cognitive load associated with tool use, and foregoing tedious syntax or data analysis so that students can focus on the salient and critical aspects of the complex inquiry of scientists [8], [14]. ML has been postulated as difficult to teach at the middle school level because students have trouble understanding abstract concepts, especially in quick, isolated interventions of only one or two class periods [15], [16]. This project will provide a robust design and implementation of a week-long curriculum that will allow us to understand how students learn to use CS and ML practices in the service of carrying out science investigations [17].

Contextualizing computational practices in the context of seismology. The SeismicML project materials are aligned with the ACSS as well ML competencies derived from the AI Literacy Standards [18] see Description of SeismicML Instructional Materials [18]. These ML competencies include understanding humans' role in AI, how computers learn from data, the importance of critically interpreting data, and how sensors play a role in collecting large datasets and interfacing with computers (Long & Magerko, 2020). We recognize that each scientific field uses these practices in a different way and that a field's unique methods and practices are "learnable and valued dimensions of disciplinary work, both tacit and explicit, that people develop over time in a specific place" [19, p. 1094]. In other words, the conditions for use of the practices arise directly out of the context of activities in each field. For example, seismologists filter and visualize seismic wave data from past events in order to train and refine ML models and then investigate real-time incoming data for specific seismic phenomena. None of these individual practices is exclusive to seismology. But CS and ML manifest themselves uniquely during these scientific endeavors [20] and a combination of these practices has proven valuable for conducting research and investigating the variety of natural and human-caused seismic signals [21]. By actively engaging students in discipline-specific knowledge, tools, and practices, they can acquire a rich understanding of the problem context as well as of the knowledge, tools, and practices themselves [22].

The need for a locally relevant CS curriculum. Theoretical and empirical research suggests that personally relevant instruction results in higher engagement and greater likelihood of successful knowledge revision [23], [24]. It has also been suggested that inclusion of real-world problems

emphasizes the interdisciplinary nature of the sciences and their relevance to students [25]. Relevance can be considered to consist of three different dimensions: individual, societal, and vocational [26]. For science teaching, this means that relevant education must contribute to learners' intellectual skill development, promote learner competency for current and future societal participation, and address learners' vocational awareness and understanding of career chances. Each of the three dimensions encompasses a spectrum of present and future aspects [26]. In the individual dimension, the SeismicML project will connect students' learning of seismic waves to their lived experiences, such as the 2018 Anchorage earthquake that shut down schools for a week [27]. From the vocational dimension, the project will also provide information and background for future employment by exposing students to and improving their understanding of authentic science and computational practices. From the societal dimension, the project will develop students' ability to make connections between this project's classroom-based seismic curriculum and their lives outside of school. By contextualizing the inquiry into local seismic phenomena, we can situate the context to the community in which the science is being learned. These internal and external justifications provide many entry points for students to feel relevance, and thus motivation, throughout the SeismicML curriculum.

Description of SeismicML Instructional Materials

Computer science is the study of how computer hardware, software, and algorithms can most effectively be applied to solve problems [28]. Educational researchers have identified several broad CS categories consisting of a core set of computational skills and practices essential to and inherent in authentic CS practices, including algorithms and programming, data and analysis, and computing systems (ACSS, 2019). In recent years, authentic CS practices have increasingly included innovative methods, such as ML [29]. Machine learning is a subset of AI (itself is a branch of CS) that focuses on using data and algorithms to enable computers to imitate the way that humans learn. Specific advantages of ML include easy identification of trends and patterns, continuous improvement as the algorithms gain experience, and the ability to adapt an ML algorithm to other computational problems [30]. To help define the ML practices and knowledge in the SeismicML curriculum, the project will use ML competencies derived from the AI Literacy Standards [18]. The project will integrate these CS and ML standards with science learning goals, crosscutting concepts, and practices defined in the Next Generation Science Standards (NGSS). These standards will be used to guide curriculum and tool design, teacher support materials, and to prepare teachers for implementation.

ACSS and ML Competencies. The ACSS *Data & Analysis* standards (7.DA.S.01, 8.DA.CVT.01, 8.DA.IM.01) focuses on developing and implementing computational tools to collect, transform, and create multiple visualizations of data, as well as refining computational models based on the data they have generated. This aligns with ML competency 12, which recognizes that computers often learn from data, especially ML models. The ACSS *Algorithms & Programming* standards (8.AP.A.01, 8.AP.PD.03) focus on using flow diagrams and pseudocode to solve complex problems and systematically testing and refining programs using a range of test cases. This aligns with ML competency 9, understanding the steps involved in ML and the practices that each step entails, as well as ML competency 13, which focuses on critically interpreting data to describe how outputs of an initial dataset can affect the results and refinement of an algorithm or program. The ACSS *Computer Systems* standards (2-IC-21, 2-IC-22), which addresses the need for students to design and refine projects that combine hardware and software to collect and exchange data, aligns with ML competency 15, which recognizes the importance of understanding what sensors are and recognizing that computers perceive the world using sensors.

NGSS Standards. The SeismicML project addresses two of the disciplinary core ideas of the NGSS related to Earth and Space Science: ESS2: Earth's Systems (ESS2.B: Plate Tectonics and Large-Scale System Interactions) and ESS3: Earth and Human Activity (ESS3.B: Natural Hazards and ESS3.C: Human Impacts

on Earth Systems). In addition, the project addresses three science practices: *planning and carrying out investigations*, *analyzing and interpreting data*, and *using mathematics and computational thinking*. The project materials also focus on the crosscutting concept of *patterns*.

The Dataflow programming interface

This project will build on the previously developed and NSF-funded block programming interface called Dataflow [31], which has the ability to connect to live hardware sensors, such as seismographs. Using Dataflow, students can write programs that import, process, and output data by connecting blocks (See Figure 1). Students will import data from seismic sensors, filter and transform the data, run data through an ML model trained to identify and classify seismic waveforms, and create multiple visual representations of the results (Figure 1). Using block-based programming allows learners to concentrate on the underlying programming concepts by providing visual cues that guide learners towards creating useful programs [32]. With the SeismicML version of Dataflow, ASD middle schoolers with little to no previous coding experience can focus on using this computational tool to carry out scientific inquiry without needing to learn complex syntax [33], [34]. To input seismic data into Dataflow, the project will use

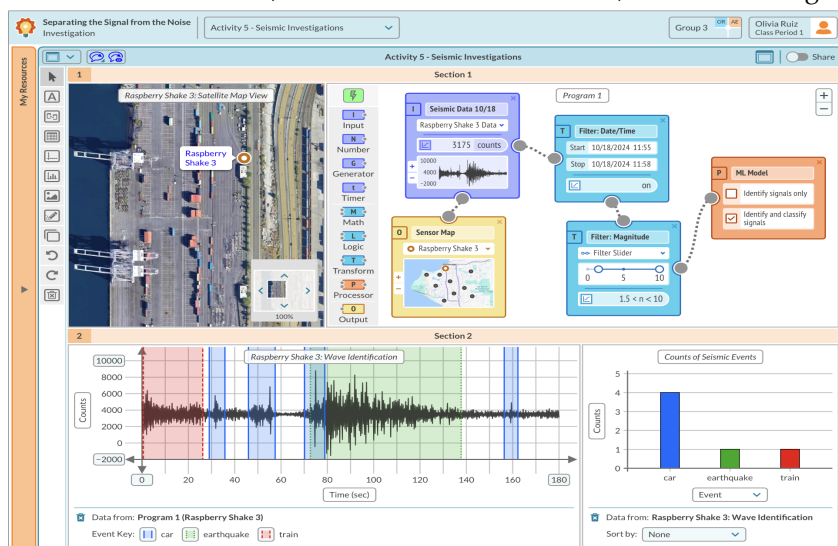


Figure 1. The Dataflow programming interface. A mock-up of the Dataflow interface coupled with the Raspberry Shake seismometer. This example shows the real-world location of the seismometer (top left), the different blocks and connections that comprise the program (top right), a visualization of filtered seismic data and associated identification of seismic events by the ML model (bottom left), and a graph of the counts of seismic (bottom right).

Raspberry Shake (RS) 3D seismographs. These sensors can be installed on the classroom floor or on a table and immediately start recording seismic signals, including all magnitudes of local seismicity as well as larger earthquakes from across the globe. In addition, teachers and students will have access to RS's full seismic database of over 2,000 sensors throughout the world, including several that are installed throughout Anchorage. This high-quality and accurate seismic data will serve as the basis for students' investigations of seismicity.

Separating the Signal from the Noise Curriculum

The project will develop a one-week curriculum module that features computationally integrated, inquiry-based activities in which middle school students will explore natural and human-caused seismic events. **The overall goal of this module is to build students' scientific and computational knowledge and practices to the point where they can build programs that leverage an ML model to query and analyze real-world seismic data to answer their own questions.** Throughout the module, students will engage in authentic computational practices used in seismology such as combining hardware and software, programming, problem solving, and creating data visualizations. The module will gradually introduce new science content and new computational methods, alternating between the two to help students build the knowledge and skills necessary to conduct investigations. By the end of the module, students will understand how science inquiry and computation support the same goal. A short description of the five activities is described below. Each activity includes a framing question, and the

description highlights how CS and science concepts are interwoven. This is a draft outline that will evolve through the co-design conversations of the RPP.

Activity 1: How is seismic data collected and what does it look like to a computer? Students consider what causes seismic waves to travel through Earth and look at seismic waveform data collected by RS seismometers in their classrooms. Beginning with basic programming blocks, students will use Dataflow to create visualizations of this seismic wave data, and will learn how to interpret the time series data that represents ground motion. Students will speculate about the seismic events captured in these waves and consider the volume of data produced in 24 hours, in a week, and over a month by a single seismometer and the challenges this volume might have for individuals to explore this seismic data.

Activity 2: What events produce waveform data and how can you use the wave features to differentiate seismic events? Interpreting seismic waves requires processing the data to identify events, to classify the events, and to differentiate sources between human and natural events. In order to identify events and classify them, students in this activity will use build programs in Dataflow to visualize one seismic event at a time and compare the seismic signals of these events. Students will learn about the key attributes of a seismic wave, including the amplitude, frequency, wavelength, and duration. Students begin to understand how sources of seismic waves (i.e., earthquakes, landslides, construction noises, etc.) produce distinct seismic signals that can be used in classification and learn how a seismic signal can be used to classify the source of that signal. Seismic data always includes background noise or interferences with many signals and can sometimes mask the signal of interest. Students consider ways in which human labeled data might not be able to keep up with the volume of data produced by seismometers and how frustrating it might be to miss the signal if the noise is overwhelming.

Activity 3: What is the value of using an ML model to identify and classify seismic waves? Mimicking the sequence of processing and analyzing data developed by scientists, students will develop algorithms to automate data tasks using ML. Students will build several programs for differentiating between event types, and for processing large amounts of data to look for scarce events such as large earthquakes. Students will learn how scientists develop methods for identifying signals from the noise and how scientists build databases of labeled seismic data that contain representations of many possible seismic signals in order to train ML models. Students will create Dataflow programs to add trained ML models to their programs and add additional filter blocks to understand how to modify ML models to adjust them for specific analyses. Students will then import seismic data from multiple RS seismometers and reason about the advantages of ML models over human labeled models when dealing with seismic time series data from many seismometers.

Activity 4: What seismic events are recorded in the waveform signals local to the school? To reinforce the ML analytic approach, students will characterize the local waveform signals collected by the RS seismometer in their school. Each class will develop algorithms to process the seismic data and develop a data visualization of events registered on their classroom RS. Students will develop programs to investigate and identify the different sources of seismic waves and the frequency of each type of event. Students will explore how to filter data for specific dates and times, magnitudes of events, and types of events. Students will learn how to analyze the outputs of the ML process, and to communicate the results of the investigations. Students will also combine data from RS sensors, apply multiple filters, and run the transformed data through the ML model in order to identify how the same events can be registered by multiple sensors in their local area.

Activity 5: What is the likelihood that [an earthquake] will occur in Anchorage? In this final activity, students will be scaffolded to conduct a self-directed ML-based inquiry investigation with the seismic data collected from RS sensors around Anchorage. Students will be required to use Dataflow to build programs, conduct analysis of the data using ML, and communicate the results of their research to the

class. Student explorations might include: “Has an earthquake occurred in Anchorage on my birthday in the last 10 years?” or “How many Raspberry Shakes recorded the earthquake that shut down our school in 2018?” This activity serves as a summative assessment to understand students’ ability to create Dataflow programs to carry out scientific inquiry.

An integrated learning task example

Olivia and Anik, working in Activity 5, are trying to figure out if there were any earthquakes near their houses in the past year. Since they both live in northern Anchorage, they filter the data for the Raspberry Shake sensor closest to their homes. In the satellite view, they see that the sensor is located at a shipping dock next to an inlet with a main road and train tracks running alongside it. Olivia sets up an “input” block that retrieves data from Raspberry Shake 3 (purple block, Figure 1). She knows that if she connects it to a “transform” block, she can filter the data for the specific date and time (green block). Olivia and Anik set a time filter for one year back from the present. They connect a second “transform” block to filter the data for any signal greater than magnitude 1.5. Excited to test the ML model block to quickly analyze the entire years’ worth of data, they connect the “transform” block to the “ML model” block. They wait a moment as the ML model runs the filtered data and produces a bar graph with hundreds of counts of signals from cars and trains in the past year, but only one earthquake. Intrigued, Anik zooms in on the time around the earthquake. He adjusts the date/time “transform” block to focus on the three minutes around the time of the earthquake, then runs the program again. Once the code completes the analysis, Olivia and Anik notice that this big earthquake created a seismic wave larger than any of the other signals around it. They are eager to describe their findings to their class and their families to find out if others remember the shaking that this earthquake would have caused!

Research Plan

To ensure the effectiveness of the SeismicML project materials for the Anchorage School District (ASD) at the center of this RPP, we employ a mixed methods Design-Based Implementation Research (DBIR) approach [11], [35]. DBIR requires collaboration across researchers and communities to develop “evidence-based improvements” [11] to classroom innovation. The RPP at the heart of this project is composed of teachers, a district science leader, seismologists, education researchers, and technology and curriculum developers, with all parties primed to contribute in meaningful and productive ways. In response to state legislation requiring additional CS instruction at all grades, ASD has been looking for specific ways to incorporate CS units into the K-8 science curriculum. At the same time, education and science researchers on the SeismicML project seek to investigate how to translate CS and ML practices for engaging students in authentic science investigations. Together, this well-defined RPP will research solutions to address the need for CS in ASD K-12 curricula, leading to the joint development and execution of this proposal. In this way, the RPP is committed to co-designing mutually beneficial materials with distributed expertise [36], [37] and DBIR allows us to conduct research that is centered on the needs of the community. The intent of our DBIR process is to shape the curriculum to maximize its value for the participating Alaskan teachers and students as well as the education research community.

Methodological framework. We will employ the lens of Consequential Learning (CL) [38] to understand and evaluate the project across cycles of design, implementation, and analysis. Consequential learning attends to the flexible and wide-ranging aspects of the temporal and spatial dimensions of learning, through socially negotiated interactions involving people, technologies, and tools [38]. Our work with CL aims to engage students in authentic disciplinary practices, as work is “consequential” when it addresses authentic problems (Davis et al., 2024). Through these authentic practices, we will create pathways to extend learning in personally relevant directions [38]. Creating trajectories that support CL involves leveraging students’ funds of knowledge [39]; therefore, we will draw on learners’ background knowledge and experience of earthquakes in the design of project materials. Using a CL lens guides our

data collection and analysis by focusing on local, real-world contexts and connections to students' and communities' experiences.

CL also emphasizes how concepts are not solely mental constructs but are distributed across people and technologies within specific practices. This perspective implies that factors, including students' attitudes, are integral to how individuals interact with and contribute to conceptual practices. Therefore, the project's analysis will also be attuned to students' attitudes toward using computational methods to build knowledge, aid in their scientific investigation, and add value to the inquiry process. Furthermore, CL recognizes that disruptions to representational infrastructures (e.g., changes in tools and practices) often create opportunities for learning, as changes in tools and practices are bound up in the evolving contexts of their use. These disruptive events often allow individuals to rethink and renegotiate practices, leading to innovation and adaptation [40].

Through the introduction of the Dataflow programming interface and associated curriculum into a science classroom, we will be able to trace how students use and adapt their conceptual understandings throughout the module. Similar to recent Knowledge Integration (KI)-based research [41], we employ epistemic network analysis (ENA) to investigate student knowledge structures or networks. ENA involves qualitative coding that is then analyzed quantitatively (noting the frequency of codes that co-occur, see Figure 3) with a focus on the creation of a visualization of the ways and extent of connections (see Figure 4) as well as network analytics (e.g., network density, cluster analysis).

Our CL-informed ENA is distinguished from a KI approach to ENA by focusing on conceptual change from a sociocultural perspective. This perspective guides our choice to investigate student learning gains in part using ENA of classroom discourse. This will offer evidence of the module's support of students' development of substantial connections among science content knowledge, CS and ML practices, and locally relevant seismic phenomena. These connections offer an alternative way to consider students' understanding of a topic and complement traditional knowledge assessments such as the embedded and summative assessments in the module. Specifically, a collective ENA will focus attention on a class as a whole, which will offer a wider lens on a class's understanding and framing of these key concepts and aligns with the sociocultural perspective of CL. ENA leverages and supports the strengths of this project in that all aspects of the science content, CS and ML practices, and localization can be assessed and considered together, including how they support each other in students' collective knowledge structures, or network models. See Data Collection and Analysis section for more information.

The DBIR Work Plan

Design Cycle 1: October 2025 to September 2026

Curriculum module development. Informed by the research literature, NGSS, and ACSS/ML frameworks, the project staff including partner teachers will develop performance expectations for the project's module for content understanding, data and model sensemaking, and development of CS and ML. A potential performance expectation that integrates NGSS, Alaskan CS standards, and ML competencies might include: *Using computational tools and models to collect and transform seismic data, students will construct an explanation based on evidence for patterns in human-caused seismic waves, such as car noise.* Such performance expectations will emerge from and evolve through iterative co-design with ASD partners. From October to May, we will regularly meet with teachers in monthly meetings to co-design early drafts of the curriculum module, discuss ways to contextualize the module within their students' lives, and ensure the articulation of how computer programming and computer science practices are essential skills. From June through September, the online module and assessment instruments will be developed in the CC authoring system.

Develop and test the Dataflow programming interface with scientists, teachers, and students.

Curriculum and software developers at CC in partnership with the seismologist at UW will translate ML

models used by scientists, integrate training sets, and develop unique Dataflow blocks for student use. Through an iterative process the prototype will be tested through think-alouds in the classrooms of the three partner teachers. These sessions will occur while development on the Dataflow programming interface is ongoing to allow for quick iteration of key features and testing of bugs in the software. The partner teachers will implement the prototype of the programming environment and early versions of the curriculum in order to gauge students' reactions to each. The goal is to focus on the user experience of Dataflow, assessing the difficulty of coupling real-time data input from RS sensors with programming and ML modeling, and identifying programming support features critical for students to effectively use the tool in inquiry investigations.

Hold an early summer co-design summit. During the summer, the full RPP team including teachers, curriculum developers, scientists, and researchers will attend a three-day summer co-design summit. Major activities include: (1) testing and feedback of the Dataflow interface, (2) finalizing the curriculum module, (3) determining implementation strategies for teaching with online, computationally integrated materials, (4) beginning the curriculum module's Teacher Edition, which will contain teaching tips, discussion points, and exemplar answers, and (5) planning the logistics of the implementations.

Design Cycle 2: October 2026 to September 2027

Pilot test module and instruments. Beginning in October 2026, version one of the module will be implemented in the three pilot teachers' classrooms as part of their typical nine-week ASD middle school "Earth and Geologic Changes" science unit. This unit includes subunits of "Plate tectonics" and "Earth's changing surface, volcanoes, and earthquakes." The classrooms will be observed by the science coordinator of ASD who is on the project team and has multiple years of experience using Raspberry Shakes in classrooms with students. Classroom observations will focus on the support students need to carry out computationally integrated Earth science inquiry investigations with real-world seismic data and student experiences with Dataflow. We will collect audio recordings of classroom discourse throughout the implementation of the module in the classrooms of all three partner teachers for ENA analysis of the pilot implementation. We will also conduct post-implementation interviews with the three pilot teachers to explore their experience in (1) teaching with computationally integrated science content, (2) the differences between this module and their typical instruction, and (3) teaching a locally contextualized curriculum.

Conduct ENA analysis. Using the recordings of classroom discourse from the three classrooms of the pilot implementation, we will conduct an ENA analysis that focuses on the change in students' connections between three major aspects of the module that we hypothesize will be impacted by the SeismicML curriculum: science content knowledge, CS and ML practices, and locally relevant phenomena. This ENA analysis will focus on critical moments of classroom discourse from early on and at the end of the pilot implementation in each classroom. This will allow the project team to understand the efficacy of the module for enabling students to make connections between these three aspects and will serve as an essential analysis to inform module revisions.

Revise the module and instruments. The SeismicML team, including participating teachers, will analyze students' responses to embedded questions in the curriculum module, students' Dataflow programs in the module (all captured automatically online), and a student attitudes survey. The SeismicML team will collaborate to revise the module and the Dataflow workspace. We will also continue co-designing the Teacher Edition that will accompany the materials. Through bi-monthly Zoom meetings with teachers, the team will ensure that the curriculum and teacher materials are centered around teacher and student needs.

Provide a professional development workshop. In the summer, the three pilot teachers, supported by the full project team, will run a professional development workshop for three additional ASD teachers

who will implement the module in Design Cycle 3. The workshop will focus on (1) science content and practices, (2) CS and ML knowledge and practices, and (3) how to implement the online module while helping middle school science teachers further contextualize the Dataflow programming, Raspberry Shake data, and overall content to students' everyday lives.

Design Cycle 3: October 2027 to September 2028

Field test module and instruments in additional middle schools. During the school year, the three teachers who co-designed the curriculum and the three teachers trained in the Design Cycle 2 professional development will administer pre-surveys (described below) to their students, facilitate students' use of version two of the *Separating the Signal from the Noise* curriculum, and administer the student post-surveys. A classroom observer from the project team will be on site throughout the implementation to make observations and collect audio recordings of classroom discourse for the purpose of robust ENA. Finally, we will conduct post-implementation interviews with all six teachers in the same way as Design Cycle 2.

Conduct ENA analysis. Researchers and teachers will co-identify critical instances of classroom discourse, one early on and one towards the end of the module. This will illustrate any changes over the course of the module in students' cognitive connections among science content knowledge, CS practices, and locally relevant phenomena in each of the classrooms. We will compare classroom discourse associated with versions one and two of the curriculum for the initial three pilot teachers and compare the discourse associated with curriculum version two in classes by the pilot teachers to the three new teacher implementers. This comparison will illuminate the affordances of more experienced teaching in terms of CS and ML and a revised curriculum.

	YEAR 1				YEAR 2				YEAR 3			
RPP Activities	CC	ASD	KSU	UW	CC	ASD	KSU	UW	CC	ASD	KSU	UW
Materials Dev & Refinement												
Flow Programming												
Curriculum												
Instruments												
Module Implementation												
Co-design summit												
Pilot testing of materials												
Observations & interviews												
Teacher PD												
Research												
Data collection												
Data analysis												
Dissemination												

Figure 2 The SeismicML timeline highlighting the RPP members' activities. The dark color represents the lead for activity and the lighter color indicates supporting the activity. When all are dark, the work is evenly distributed between partners.

Data Collection and Analysis

We will utilize several data sources to explore the extent to which the module improves students' science content knowledge and their CS and ML practices as well as the consequentiality of connecting the learning materials to students' local community. Classroom observations, recordings of classroom discourse, student attitudes surveys, and teachers' field notes throughout all aspects of their participation in co-designing, revising, and implementing the materials will be leveraged to answer the research questions.

Teacher Interviews. We will inductively analyze teacher post-implementation interviews to inform iterative development of the module and the teacher support materials.

Classroom Discourse and Epistemic Network Analysis. Given the dual goals of developing a meaningful CS and ML Earth science curriculum module and focusing on local relevance for engaging

students in STEM, we will use network analysis methods of classroom discourse [42], [43] as they support nuanced investigation of Consequential Learning. The team will investigate students' CL, operationalized as connections among science content knowledge, CS and ML practices, and localization. Network models illustrate knowledge and connectedness at one point in time [44]. Models can be constructed for multiple time points to assess changes over time in students' knowledge networks. A collection of these models of different time points can show changes students' knowledge that can be missed by traditional pre- and post-tests [45]. Because we aim to promote students' CL through the module as analyzed through epistemic network analysis, we will collect audio recordings of classroom discourse throughout the implementations in Design Cycle 2 and in Year 3. The team will conduct emergent coding within three core areas of science content knowledge, CS and ML practices, and locally relevant earthquake phenomena. These codes can be organized under broader categories; the number of times any two categories occur within the same open-ended response (called co-occurrences) will be counted and network models will be created [43], [46] using ENA (See Figure 3).

To investigate how students' collective class networks change over the implementation, we will construct models using the software UCINET for critical time points (early and late in the curriculum) co-identified with teachers during module implementation. The RPP team, including the teachers who co-designed the module, will qualitatively and quantitatively analyze and compare the network models for different classes. Qualitatively, we will describe the types of connections and relative strength of the connections (associations). Quantitatively, we will determine how connected aspects of the models are by calculating association levels, weighted averages of co-occurrences using the agglomerative clustering method [47], an accepted network analysis method [48], [49] recommended by [50] in their review of ENA in science education. Some aspects of each model will be more connected to some aspects than others, representing a "cluster." The number of clusters will be counted and their composition within a class's model evaluated to consider why those aspects are connected strongly [45]. A model with fewer clusters and higher association levels is considered to represent a more connected framework and a more cohesive conceptualization (See Figure 4).

Additional network analysis metrics such as network density will be calculated as well [50]. In Design Cycle 2 ENA analysis, teachers will review and provide feedback on the network models to inform modifications to the module

Potential Class Discussion Composite Matrix								
	Data	Model	Seism	EQ	Ampl	Pattern	ML	Local
Data	0	12	8	15	4	5	3	7
Model		0	3	6	1	4	6	5
Sesim			0	10	5	3	4	8
EQ				0	3	7	5	9
Ampl					0	2	0	3
Pattern						0	4	6
ML							0	4
Local								0

Figure 3. Example hypothetical matrix where each number represents the total frequency of each co-occurrence per pair of concepts in a collective class discussion.

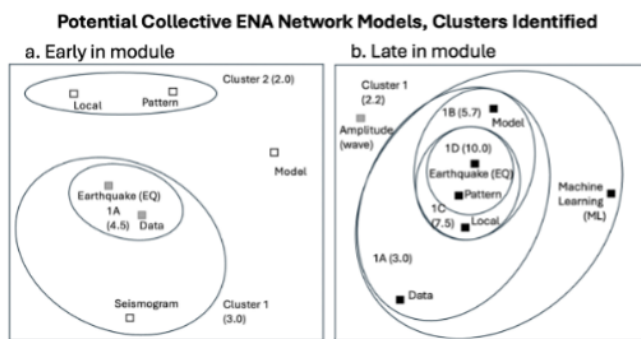


Figure 4. Hypothetical collective ENA network models (a) early and (b) late in module. Squares represent individual codes of epistemic elements, with darker colors representing higher quality knowledge. The models were transformed using multidimensional scaling to identify clusters, or sets of elements students connected to each other strongly, indicated by ovals. The higher the value in parenthesis, the more strongly connected the elements. Model (a) (early in module) includes two clusters with relatively low associated values and a less connected framework compared to Model (b) (late in module) which has a more cohesive epistemic framework with one nested cluster and higher association levels.

and teacher support materials, as needed to further develop CL. In Design Cycle 3, the networks for students engaging in the module will be compared between Y2 and Y3 classrooms.

Surveys. Quantitative measures include two surveys that students will complete prior to and after using the module: a Computer Attitudes Survey and a Relevance Scale. To measure the effects of locally relevant computing learning experience on the change of middle school students' computer attitudes, we will analyze students' responses to a Computer Attitudes Survey [51]; $\alpha = 0.736$) that measures (1) students' interest in studying computers, (2) students' attitudes towards computers, and (3) students' understanding of computer concepts. The Computer Attitudes Survey will be administered before and after students engage with the module. Our focus is on how individual students' participation in computational practices and their dispositions towards the practices changes over the course of the implementation, especially how it relates to the disruptive representational infrastructure (i.e., the tools, technologies, and materials developed in this project) [38].

To assess students' perceptions of the relevance of the curriculum, we will use the [52] Relevance Scale to evaluate how students see personal, contextual, and future relevance for their classroom content. The unidimensional scale consists of 12 Likert-style items with attained internal consistencies of $\alpha \geq 0.90$.

Analysis of these data will engage a within-person repeated measures MANOVA (multivariate analysis of variance) to evaluate the extent to which students' scores of content knowledge and educational relevance within science change over the course of the implementation. As warranted, standard error estimates will be adjusted using a sandwich estimator to accommodate nested data. This approach accounts for potential family-wise error attributable to the use of multiple measures completed by each participant and can detect time point by time point and aggregate effects over time, as well as avoiding potentially inflated Type I error rates. In the field test that is part of Design Cycle 3 we will employ a hierarchical linear model to account for nesting of students within schools and permit estimation of potential differences as a function of school location and population.

Module Data Collection and Analysis. To explore student learning and engagement, embedded prompts in the online module will elicit students' thinking using (1) multiple-choice items, (2) written descriptions and explanations, and (3) Dataflow programming. Students' responses to embedded assessments will be collected automatically by the server that hosts the online module and analyzed to investigate the extent to which students learn geoscientific and computational concepts. Following the pilot implementation, we will look at all student responses to embedded assessments items to help guide revisions. We will use analytic induction methodology [53], [54] to deliberately and cyclically code written descriptions and explanations and to investigate individual student and class perceptions and attitudes, with specific attention to the role of local, real-world connections emphasized in our CL lens. This approach will identify meaningful seismic data investigation activities situated within and across classes of students, interrogating the interpretations of those activities, and then returning to the data for possible disconfirming evidence. Following the field test implementation, embedded assessments will be analyzed in relationship to ENA analysis and survey results. Together, these will investigate individual and class learning outcomes to iteratively improve the module.

Dataflow snapshots. To understand the affordances of students' use of CS and ML to carry out scientific investigations, we will collect students' programs at several points throughout the module. Informed by the relevant CS practices of the ACSS and the ML competencies identified in the AI Literacy Framework [18], instances of computational practices afforded by Dataflow will be tagged. The practices of interest include students' knowledge and skill in combining hardware and software, programming, problem solving, and creating data visualizations. Each students' Dataflow programs will be coded by a researcher using a rubric to identify these computational practices. In these analyses, we will focus on students' ability to (1) translate written instructions into block-based programs, (2) use combinations of

filters and sensors to manipulate large seismic data sets, (3) use the ML model to conduct science inquiry, and (4) create data visualizations to use as evidence in answering scientific questions.

Summative assessment activity. The fifth activity of the module will serve as a summative assessment of students' ability to carry out computationally integrated inquiry investigations. We will use their responses and programs to assess students' ability to: 1) conceive a locally relevant scientific question that can be answered through computational analysis, 2) devise a method that leverages ML to answer the question and their ability to translate that methodology into a program, 3) make sense of the data produced by the program, and 4) critically interpret the outputs in the context of their initial question.

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; Researcher: Lore; DRL-1841928; \$1,978,274; 8/2016-9/2023).

Intellectual merit: The project designed innovative technology-based opportunities to enrich both science learning and exposure to block-based programming and computational thinking through real-world authentic computational geoscience research contexts. The project advanced the field's understanding of how to support students' creation of computational visualizations and analysis of real-world data in order to improve their understanding of geohazards. **Broader impacts:** The project equipped students with computational and problem-solving skills and greater knowledge of how science research can inform society about hazards and risks. By integrating computing into Earth science classrooms, the project brought computational thinking to a different audience than traditional computer science classes. In the course of the GeoCode project, over 100 teachers in 14 states have implemented both modules with over 3,100 students using the seismic module and over 4,800 students using the tephra module. The seismic module served as the basis for an ongoing ITEST grant (DRL-2241021), designed to engage diverse students in California in locally relevant seismic investigations. **Publications:** Three scientific articles [55], [56], [57]; three educational research papers [14], [58], [59]; three newsletter articles [60], [61], [62]; five conference presentations; and one doctoral dissertation.

Collaborative Research: Frameworks: Seismic Computational Platform for Empowering Discovery (SCOPED). (PI: Denolle; OAC-2103701; \$660,591; 9/2021-8/2025). **Intellectual merit:** The SCOPED project has developed a hybrid cyberinfrastructure to unify model-driven and data-driven discovery through Cloud and HPC computing, and development and containerization of state-of-the-art open-source software scalable to large data volume and computation. **Broader impacts:** The project fosters collaboration among 5 institutions, 10 early career researchers, the development of teaching materials training workshops, and the broadening of the platform to the community. Seismological discovery at that scale provides cross-disciplinary inputs to geodynamics, hydrology, geodesy, and natural hazards. Denolle is also Co-PI on **Machine Learning Training and Curriculum Development for Earth Science Studies** (NSF CyberTraining Grant #2117834; \$995,817, 9/2021– 8/2024). **Intellectual merit.** This project developed the GeoScience Machine Learning Resources and Training (GeoSMART) framework to build a foundation in open-source scientific ecosystems and general ML theory, toolkits, and deployment on Cloud computing platforms while developing an open-curriculum for undergraduate graduate-level courses. **Broader impacts;** The project provided training in open-source ML toolkits and data science skills, trained early career scientists during workshops, and taught over 100 students in class at UW. **Publications:** [63].

Collaborative Research: Origin of Large Brains of Cetaceans (Co-PI: Mulvey; 214256; \$51,497; 09/2022-8/2025). **Intellectual merit:** This project integrates geoscience and life science to investigate relative brain size, high frequency hearing, and petrosal bones of Eocene cetaceans using CT scans and

brain size, hearing, and number of brain neurons of modern day cetaceans. Cetacean EQ increased at a rapid rate in the Eocene, at least more rapid than at any other time during cetacean evolution. This increase in brain size predated the origin of high-frequency hearing. **Broader impacts:** The project promoted collaboration of high school students from Ohio and Alaska, and incorporated Ohio students as interns in the grant's research group. Educational research on high school student interns in the research group provides guidance for how to meaningfully integrate high schoolers into a research group in ways that support meaningful engagement in authentic science as well as research group outcomes. **Publications:** [64], [65], [66], [67], [68], [69].

Partners and Responsibilities

Christopher Lore will serve as Principal Investigator. He will direct the development of the modules and curricular materials and be responsible for the overall coordination and budgeting of the project.

Amy Pallant (Co-PI) will guide the development of the curriculum module and teacher support materials, as well as advise on all aspects of the project.

Bridget Mulvey, Ph.D. (Co-PI) will lead the education research, especially research on classroom discourse (using ENA), teacher interviews, and qualitative artifacts collected within the module. She will manage the research plan, guide the data collection and analysis, and coordinate publication efforts.

Marine Denolle, Ph.D. (Co-PI) will provide scientific expertise, share code and the ML model developed for visualizations, and advise on the seismological and computational aspects of the project.

Jennifer Pickering, Ph.D., the ASD science coordinator, will organize the ASD teachers, aid in the implementation of the modules, help conduct the co-design and professional development workshops, and leverage her expertise in working with Raspberry Shakes to teach students about seismic waves.

The SeismicML RPP includes three middle school teachers. **Brian Gehring** is a science teacher at Steller Secondary School in the Anchorage School District. **Madison Berman** is a science teacher at Steller Secondary School in the Anchorage School District. **Chelsea Fullman** is a science teacher at Clark Middle School in the Anchorage School District. Each of these ASD teachers will provide real-world practical insight into classroom challenges with the materials and field test the SeismicML materials. They will leverage their weekly Professional Learning Committee professional development time to meet with RPP partners and ensure the materials development meets the district's desired outcomes. The ASD team members will focus on iterative co-design, testing, and improvement of the SeismicML materials.

Evaluation

Dr. Colby Tofel-Grehl, principal consultant for Empirical Basis, LLC, will conduct the external evaluation, which will be formative in design, with annual summative reporting. Her scholarship interrogates the structures, systems, and practices in STEM learning environments, with particular expertise in developing and sustaining research-practice partnerships. The evaluation will rigorously monitor program activities from an external perspective, commenting on challenges, interacting with all RPP partners and stakeholders, and helping connect iterative and ongoing research findings with project goals. Dr. Tofel-Grehl will write annual reports and a final summative report, which will be included in annual reports to NSF. The evaluation will include three components:

Efficacy and alignment with the RPP's goals and objectives. Evaluation will closely follow each project phase and advise on design and direction through regular video conferences and appropriate face-to-face meetings with a focus on: (a) adherence to plan (timeline, recruitment, curriculum and technology development); (b) implementation challenges (PD, fit of locally relevant curriculum, and integration of CS and ML practices with Earth science content), and (c) how the research effort informs RPP goals. Evaluation of the project will draw from Henrick and colleagues' "Indicators of research-practice partnership health and effectiveness: Updating the five dimensions framework" [70] with particular focus

on Dimensions 2 (*Engage in research or inquiry to address local needs*) and 4 (*Engage with the broader field to improve educational practices, systems, and inquiry*). Questions include: To what extent is the RPP performing according to plan? What are the barriers in each phase? What are the challenges inherent in integrating CS and ML practices with Earth science content in middle schools? To what extent is seismic phenomena a relevant topic to teachers and students in Anchorage? What unique value do the computationally integrated materials offer?

Alignment with research design. Evaluation will document how the research activities and research plan capture evolving outcomes and necessary modifications to meet the project goals. Dr. Tofel-Grehl will provide independent and unbiased perspectives on research findings, including collection of student and teacher surveys where they can provide feedback about the Dataflow programming interface and its perceived impacts on their learning. Open-ended items will invite suggestions for ways to improve the CS and ML integration. Questions include: To what extent are the research questions being answered? What is the value of these questions to RPP partners, teachers, students, and the field? What additional data are not being collected, and why? What factors connect Earth science understanding with CS and ML practices? What teacher and student support is critical for learning?

Broader Outcomes. In Year 3, Dr. Tofel-Grehl will investigate the potential for the replicability of the pedagogical model designed and conducted in the SeismicML project. This review will aim to understand how easily the materials, including Earth Science content, Dataflow interface, and teacher support materials might be replicated elsewhere without the benefit of a fully supported RPP.

Dissemination

The Dataflow programming interface, module, surveys, and teacher support materials will be licensed under open-source code and open content licenses and will be freely distributed to teachers, curriculum designers, and researchers on CC's STEM Resource Finder. The release of the materials will be accompanied by announcements and blog posts to communities of interest – both Alaskan schools and schools across the country. All partners will promote project materials and research findings through presentations and workshops at conferences (e.g., National Science Teaching Association, National Association of Research in Science Teaching, and International Society of the Learning Sciences) and through articles published in peer-reviewed journals in science education (*Journal of Research in Science Teaching*, *International Journal of Science Education*, *Science Education*, and *Journal of Geoscience Education*), learning sciences (*Journal of the Learning Sciences*), and teachers (*Science Scope*). The @Concord biannual newsletter, distributed for free to over 60,000 digital subscribers, will be another communication venue. The dissemination efforts will engage both academic and non-academic communities.

Broader Impacts

Artificial intelligence is increasingly important for success in school, work, and society more broadly. A curriculum module that provides authentic CS experiences, including innovative methods such as machine learning, could provide transformative impacts. The RPP will work directly with six middle school teachers and their students to engage in locally relevant science and computer science pedagogy that supports CS and ML for all students in Alaskan middle schools. The RPP aims to help ASD meet the educational goals established by the State of Alaska. By demonstrating the effectiveness of embedding computer science and ML into content courses at the middle school level, this project will produce a replicable pedagogical model for including machine learning in other STEM contexts, including algebra, physics, and career and technical courses. The project's programming interface accesses Raspberry Shake seismograph data from all over the United States, making this tool widely relevant to teachers and students from all over the country. All project materials will be made available for free through open-source and open-content licensing. Research findings will be disseminated at conferences and in research and practitioner journals.