The Pelehonuamea Project: Connecting Indigenous Hawaiian History and Computational Geoscience in Teaching Volcanism

Computational geoscience is used for volcanic risk assessment and hazard mitigation for Hawaiians. Volcanologists are constantly measuring and monitoring the six active shield volcanoes in the island chain. During the Mauna Loa eruptions in 2018, 2022, and 2023, volcanologists significantly contributed to emergency management plans by using powerful computational models of lava flow to estimate where and when lava flows would reach certain areas of the island [1]. These models were produced through years-long data collection of lava flow characteristics, remote sensing of topography, and analysis of past eruptions that were combined into mathematical models of lava flow [1], [2]. Visualizations created by these computational models helped scientists discover spatial patterns in lava flow and communicate risk to the island communities with the aim of reducing impacts [1], [3], [4].

Broadening participation in computing, science, geoscience, and the STEM workforce is critical. While computational methods are now commonplace in geoscience research, many jobs previously not conceptualized as STEM workforce are evolving due to the pervasive need for computer science (CS) and computational thinking (CT) skills. From road surveying to urban planning, job preparedness is increasingly determined by some measure of CT [5]. To prepare students for a computation-intensive employment future, it is important to build their computational competencies early. In a survey of Hawaiian employers, 55% noted that geospatial analysis is commonly performed at their organizations and 30% reported that coding languages such as Python were valuable in their work [6]. These skills are also needed by surveyors, construction teams, and others working to help Hawaiians navigate and keep safe from volcanic hazards because computational and predictive models inform road closures, school openings, and a host of everyday civic activities on the islands.

Hawaiian schools are primed for computer science and computational thinking-integrated learning materials. In July of 2021, in service to the broader needs of a computationally literate Hawaiian population, Hawaiʻi vowed "to improve digital literacy throughout the state by further increasing computer science education offerings at public schools" [7, p. 5]. Student enrollment in CS courses in the 2021-2022 school year in Hawaiʻi was low, with only 16% of students across the state enrolled in a CS course [7]. The state laid out a three-year initiative, starting in the 2022-2023 school year, in which they began increasing the computer science education offerings in public schools with the goal of having 100% of schools offering students at least one CS course or computer science content in other courses by the 2024-2025 school year. However, only 20% of schools currently meet the CS/CT instructional expectations mandated by state law [8] due to several factors, including the low availability of and enrollment in these courses, lack of teacher capacity to teach CS and CT content, the number and type of CS courses offered at each school, and the number of spots available in each course.

Earth science content is ideal for embedding CS and CT concepts. As schools in Hawaiʻi attempt to respond to the demands of the legislature for increasing CS and CT in their curricula, they are investigating alternative options to introduce these concepts in other courses. The exploration of volcanic activity, including their hazards and risks provides a rich opportunity for computational integration because it is relevant to Hawaiian students' everyday lives. Computational practices in the geosciences include coding, problem solving, modeling, and creating visualizations grounded in real-world phenomena. Such authentic geoscience practices can be made accessible to students in the way they are practiced by geoscientists when they are translated to a level appropriate for engaging students in inquiry-based activities [9].

Integrating oral history with volcano science can engage more students. To better understand historical eruptions and forecast future hazards, scientists and researchers studying Hawaiʻi have turned to Hawaiian-language newspapers, journals, stories, and chants to combine the essential geologic knowledge embedded within them with their own knowledge [10], [11]. For example, a workshop in

Hawaiʻi in 2013 [12] convened Indigenous Hawaiians and scientists in order to combine over 1,000 years of traditional Hawaiian knowledge with more recent scientific thought on Hawaiian volcanism [10], [12]. By combining knowledge that Indigenous Hawaiian histories and Western scientists hold, both communities are learning more about the knowledge within Hawaiian oral histories that scaffolds understanding of the past, confirms geologic records, and provides fertile ground for new scientific investigations involving the volcanoes [10]. Furthermore, Indigenous wisdom provides a powerful entry point for young Hawaiians to learn about and investigate local volcanic eruptions, hazards, and risks [13]. By integrating Indigenous Hawaiian volcanic knowledge and practices with Western geoscientific knowledge and practices, students can fully engage their identities and values concurrently and link their culture, lore, and sense of place to the scientific and computational enterprise [14], [15], [16].

Our research-practice partnership (RPP) will co-design authentic computational geoscience investigations. We will address the need for learning experiences that engage Indigenous Hawaiian students in a locally relevant curriculum that meets state CS standards and improves interest in CS. The RPP team will co-design, develop, and pilot an innovative approach to research and development of curriculum materials about volcanic activity, hazards, and risks. We will weave together Indigenous Hawaiian and Western geoscience knowledge by integrating CS and CT as necessary tools for conducting authentic scientific inquiry anchored in the history of the islands by: (1) integrating Hawaiian oral histories and current community lived experiences of volcanic eruptions with Western scientific knowledge to provide a rich, locally relevant understanding of volcanic hazards and risks; (2) engaging Indigenous Hawaiian students in CS and CT practices through block coding in order to conduct computational simulation-based scientific investigations; and (3) broadening Indigenous Hawaiian students' sense of agency and educational relevance in computing and geoscience to better prepare them for diverse job opportunities.

Project Goals and Objectives

Leveraging a successful existing RPP that focuses on teacher professional learning around integrating computational thinking into locally relevant computing curricula, the Pelehonuamea Project will co-design and study a place-based and community-centered, personally relevant computational geoscience curriculum module. The RPP brings together expertise from the Concord Consortium (CC) in technology and curriculum development, the teachers' and principal's expertise in Indigenous Hawaiian student learning from Waimea Middle School (WMS), and expertise in RPP development and sustainability for community-based research and mixed methods research from Utah State University (USU). WMS sit at the center of this RPP because of its school charter, which foregrounds Hawaiian culture, community, and language. WMS is the only public middle school in the town and became a Hawaiian-focused charter school to meet the needs of the community. With 72% of students qualifying for federal free and reduced lunch, 87% of students identifying as BIPOC, and 63% of students identifying as ethnically Indigenous Hawaiian or Pacific Islander, the school's rural and community profile make it an ideal candidate for engaging in research that centers Hawaiian community and culture. Thirty percent of students also qualify for special services based on migrant status, reflecting children of migrant agricultural laborers or displaced Pacific Islanders (e.g., political and/or climate refugees). As a Hawaiian culture-, community-, and language-focused charter school, the school's core values are *'Ike* (knowing), *Kaizen* (improving each day), accountability, integrity, and respect. From this framework of values, our RPP supports Indigenous Hawaiian students in developing their understanding of computer science and geoscience and builds students' computational thinking competencies for the exploration of real-world and relevant problems.

The goal of the Pelehonuamea Project is to address the need for locally relevant curriculum that meets Hawaiʻi state CS standards and improves students' interest in CS through the co-design of a culturally relevant CS and CT volcano curriculum designed around inquiries that are locally and personally relevant.

Objective 1: Expand a Hawaiian research-practice partnership and collaboratively develop a CS and CT geoscience curriculum module. This project expands on an existing RPP between WMS and USU to include the CC team to participate in a co-design process that centers students as experts. To contextualize and situate learning about volcanic eruption posed by the Mauna Loa volcano, students will conduct ethnographic studies capturing Hawaiian historical and lived knowledge about volcanic eruptions. The RPP will co-design a volcano module that will connect their ethnographic narratives to the learning goals of the activities and be used to contextualize the CS, CT, and geoscience learning.

Objective 2: Create a computational model of a Hawaiian shield volcano. The project will build upon previously developed software to create a computational model called the *LavaCoder* that will allow students to use visual block-based coding to model lava eruptions from the Mauna Loa volcano. Students will use CS/CT to model and explore the environmental variables that influence the volcanic lava flow system, define the relationships among pertinent environmental factors, create visualizations of lava flow from a volcanic vent, and analyze the data produced by the model.

Objective 3: Conduct research on students' CT and CS learning and interest, science content knowledge, and the development of their sense of agency and educational relevance during the co-design process. The RPP co-design process will serve as both a method of curriculum development and a method to investigate these jointly developed research questions:

RQ1. In what ways does incorporating students' ethnographic narratives of Hawaiian values, knowledge, and experiences of volcanic eruptions and students' participation in the co-design of a CS and CT geoscience curriculum module support the development of students' sense of agency and perceptions of educational relevance?

RQ2. How does using a culturally and geographically relevant CS and CT geoscience module affect students' interest in and attitude towards computing and computational thinking?

RQ3. To what extent does using the CS and CT geoscience module build students' computational thinking skills, computing practices, and geoscience knowledge?

Framing and Contextualizing the Pelehonuamea Project

The need for culturally responsive CS and CT. The local contextual challenges of WMS stretch well beyond a single school setting. The state of Hawaiʻi is a single district, divided into subgroupings called complexes. In the Hawaiʻi district, WMS is part of Honokaa-Kealakehe- Kohala-Konawaena complex. Throughout the complex, which spans multiple islands, only 16 of the state-approved CS courses are taught across the 19 schools. Honokaa High and Intermediate School, the school most WMS students will attend for high school, offers only two courses: computer science A/B and AP computer science principles. However, these courses are offered only once per year to students, limiting student access to a small proportion of the school. WMS itself does not currently have discrete offerings in computer science, making it impossible for it to meet the requirements of the 2021 state legislation. This means that students who attend WMS are likely to go through their entire K-12 public education with no opportunity to take a CS/CT class. Furthermore, students at WMS have also identified the lack of Hawaiʻi-centered learning opportunities as a pressing issue [16].

WMS and Co-PI Tofel-Grehl have developed and sustained a successful RPP over the past eight years. Together they have co-developed six Hawaiʻi-specific computing projects including a 3D-modeled computational circuit of Hawaiʻi's volcanoes (see Results from Prior NSF Support). To determine the potential need for and value of expanding the existing RPP, WMS and Tofel-Grehl deployed CC's Volcanic Hazards and Risk module that was developed as part of the GeoCode project (see Results from Prior NSF Support) in the summer of 2023. Pilot findings from this collaboration indicate that youth and teachers desired a Hawaiʻi-centered module that explores the lava flows they live with and the potential impacts of future eruptions. Students immediately noted that the existing module focused on tephra volcanoes and not the shield volcanoes of Hawaiʻi. Teachers and students both articulated beliefs that a geographically local computational simulation that centered their island's geologic science would be more meaningful than the existing one. Furthermore, youth and educators expressed a desire to center the stories of people living among the volcanoes of Hawaiʻi. As one student commented "we could share what it means to live with vog." Vog, the air pollution associated with volcanic eruption, impacts daily life during eruption and students felt this would be an important focus of the possible ethnographic narratives they might collect.

Culturally responsive CS and CT activities, a relatively new curriculum approach, have shown particular promise in supporting students' STEM identities when focused on youth as digital creators [17], [18], [19]. In the Pelehonuamea Project it is our aim to bring together culturally responsive CS and CT activities with science experiences, first at WMS and then at two other schools in the district, in order to engage Indigenous Hawaiian students early in their computer science education experiences.

CS and CT in the Pelehonuamea Project. CS is defined by the Association for Computing Machinery (ACM) and the Computer Science Teachers association (CSTA) [20] as the area that studies computers and algorithms, hardware and software design, and evaluation. One of the primary purposes of CS is to solve computational problems. The problem-solving approach is often related to computational thinking [21], [22], which has long been considered one of the key factors in CS education. Since Wing [23] advocated for the inclusion of CT as part of formative educational experiences in schools, many have attempted to operationalize CT in classrooms [21], [24]. In addition to CT, we recognize programming as one of the fundamental skills in CS and a vital tool to develop CT skills [21], [25], [26]. To help define CT for classroom integration, Weintrop et al. [27] grouped 22 CT practices into 4 major categories: data practices, modeling and simulation practices, computational problem-solving practices, and systems thinking practices. However, each scientific field has identified a unique set of computational methods and practices [28] that are "learnable and valued dimensions of disciplinary work, both tacit and explicit, that people develop over time in a specific place" [29, p. 1094]. In other words, the conditions for use of the methods and practices arise directly out of the context of activities in each field. In geoscience, CS and CT skills commonly practiced are related to abstraction, data analysis, modeling and simulation, and computational problem solving [27]. For example, volcanologists frequently collect data on the thickness and the distribution from past volcanic eruptions in order to develop computational models of eruptions for that volcano. They then use these models to simulate future eruptions and create probabilistic estimates to calculate risks. While none of these individual practices is unique to geoscience, a combination of these varied practices has proven valuable for answering questions and solving problems concerning the Earth and its environment [30]. In this way, CT manifests itself uniquely during scientific endeavors [31]. When students are actively engaged 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 [32].

In the Pelehonuamea Project, CT manifests itself during computationally mediated scientific endeavors [31] that are contextualized to volcanology wherein students engage in integrated activities including: (1) assembling code blocks to compute the likelihoods of future volcanic eruption hazards based around the volcano; (2) compiling, filtering, manipulating, and analyzing historical eruption data to predict the location and extent of future eruptions; (3) conducting computationally mediated investigations to understand the relationships between the amount of lava, the viscosity of lava, the rate of lava flow, and topography; (4) using data visualizations and computational abstractions to understand and communicate hazard awareness materials incorporating volcanic hazards, preparation, and mitigation strategies; and (5) using computational outputs and community population and resource maps to identify vulnerabilities in the community.

Throughout all of the inquiry investigations, the module will focus on specific programming skills and concepts [33] identified as "focal knowledge, skills, and abilities" (FKAS) for middle school computer science assessments. This project will include many FKASs, including but not limited to: (1) describing the execution that is performed by a (specific) given sequence of instructions, (2) describing and identifying elements of a loop function, (3) describing the sequence that is executed in a given program,(4) identifying a pattern from a real-world phenomenon, and (5) creating, assigning, and updating variables. Students will also employ additional common code structures such as conditionals, functions, and variable assignments. Students will express much of the computational thinking and problem solving in the investigations through block coding activities.

Design Principles for Instructional Materials

The project will apply the following design principles when developing the *LavaCoder* model and associated geoscience module. First, students will leverage computational methods to investigate complex patterns in nature. Computational models are ideal for this exploration because they are defined by a set of variables where each variable can be isolated to explore its effect on the outcome of a complex system [34]. Second, activities will be scaffolded to facilitate computer programming that drives investigations of factors related to magma eruptions by assembling code via blocks, changing variables, observing outcomes in a computer simulation of magma flow, and creating data visualizations. Third, investigations will be framed around student-developed ethnographic narratives to heighten the cultural relevance of the computational geoscience problems [28], [35]. Through alternating the introduction of computational concepts and scientific concepts, and building competence and knowledge in both domains, the design of the materials will focus on elevating student engagement and reducing frustration [36]. Prior work by this team focused on modeling volcanic ash dispersion of the Cerro Negro volcano in Nicaragua (see Results from Prior NSF Support*).* In the Pelehonuamea Project, we will model lava flows from the Mauna Loa volcano on the Big Island of Hawai'i. By contextualizing the computational model and simulating a different type of volcanic eruption, we can situate the geoscientific context to the community in which the science is being learned. We will introduce the ways in which scientists use computational practices to investigate past magma flow eruptions and simulate potential future volcanic risks based on differences in input variables for this specific volcano. This effort will anchor the formal learning to the people and locations in which the learning takes place [37].

The *LavaCoder*. Scientists who conduct volcanic risk assessments rely heavily on computationally intensive approaches. If students are to have the opportunity to explore how scientists use computational approaches to model eruptions, assess risk, and understand lava flow, there is a need to translate scientists' tools and methods for use in the classroom [38]. This project will build on the previously developed *GeoCoder* (see Results from Prior NSF Support) to create the *LavaCoder*, a computational model that translates scientific-grade numerical models of lava flow used by professionals to a simplified block-based computer programming environment. The blocks used in the *LavaCoder* are similar to other block languages such as *Scratch* and *Blockly*, which are commonly used to teach K-12 students because the blocks simplify the complex syntax associated with other programming languages and the block shapes offer clues on how programming ideas are combined [39]. Novice CS learners can focus on the

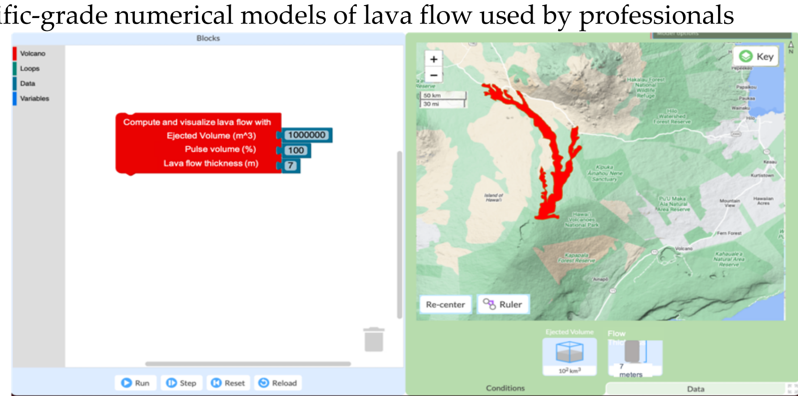


Figure 1. A mock-up of the LavaCoder showing block code (on the left) that creates the lava flow from the Mauna Loa volcano (on the right).

computational concepts and logic without being bothered by the syntax [40], [41].

Volcanologists on this project will provide the numerical models for the computational base of the *LavaCoder*. Students will use block code to set the initial conditions of an eruption, adjusting the values for eruption rate, total volume erupted, viscosity of magma, vent location, and other magma properties, and by doing so, updating the inputs to the numerical model. Through a selection of premade variables, students will be able to experiment with data types as well as simple function blocks that can be combined to create complex functions. Students will be able to connect how the function blocks work to a unique visual output related to magma eruption and flow. Thus, by combining the syntax of the blocks and the order in which they are executed in the code, students can link the code to what happens in the other representations in the *LavaCoder*. The visualization side of the *LavaCoder* will show the effusion of lava from a vent on the Mauna Loa volcano, as well as the flow of the lava, which will be guided by the topography (Figure 1). Students will model many different eruptions to explore how initial conditions affect lava thickness, how far lava will travel, and the potential of lava impacting communities near the volcano, which will be labeled on the map. Students will be scaffolded to connect the dynamically linked visual representations in the *LavaCoder,* such as the procedural block code and the magma effusion, in order to investigate impacts caused by modeled eruptions, imitating the very practices of scientists.

The Pelehonuamea Project classroom learning experiences. Below is an initial sketch of the Pelehonuamea Project module co-design effort. The community contextualization efforts outlined and the details of the students' computational geoscience module will evolve as a result of the RPP co-design work. To begin we describe how the learning experiences align with three sets of standards: the Computer Science Teachers Association standards adopted by the Hawaiian Department of Education [42]; the Next Generation Science Standards [43]; and the Hawaiian Social Studies Standards [44].

CSTA standards. The Hawaiian HB503 bill states, "Beginning with the 2024-2025 school year, all public elementary, middle, and intermediate schools shall offer computer science courses or computer science content" [45]. Learning will meet CSTA standards across two content areas: Data & Analysis (2-DA-07, 2-DA-09, and 3A-DA-12) and Algorithms & Programming (2-AP-10, 2-AP-12, 2-AP-13, 2-AP-15, 3A-AP-13, 3A-AP-16, 3A-AP-17, 3A-AP-18, and 3A-AP-21). For example, standard 3A-DA-12 (*Create computational models that represent the relationships among different elements of data collected from a phenomenon or process)* will be addressed when students use the *LavaCoder* to investigate different variables (e.g., viscosity, flow rate) that affect lava spread. When students use the *LavaCoder* to visualize where lava might flow and which parts of the community will be affected, they will engage in standard 3A-AP-16 (*Design and iteratively develop computational artifacts for practical intent, personal expression, or to address a societal issue by using events to initiate instructions*). In addition, the co-design process will engage a subset of students (see the DBIR workplan) in the following standards: 2-AP-15 (*Seek and incorporate feedback from team members and users to refine a solution that meets user needs)* and 3A-AP-21 (*Evaluate and refine computational artifacts to make them more usable and accessible).*

Science standards. The module will align with the following NGSS middle school science standards: MS-ESS2-1 (*Develop a model to describe the cycling of Earth's materials and the flow of energy that drives this process*; *ESS2.A)*; MS-ESS2-2 *(Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales; ESS2.A)*; and MS-ESS3-2 *(Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects; ESS3.B)*. The module emphasizes two science practices, *analyzing and interpreting data* and *using mathematics and computational thinking*, as students analyze past volcanic data and make predictions on future risks by running multiple experiments with the *LavaCoder*. The module also addresses the crosscutting concept of *patterns*, as students analyze multiple lava flow model results to reason about which areas on the map are most at risk of volcanic impacts.

Hawai‘i social studies standards. By integrating the ethnographic narratives into the module, the Indigenous wisdom and cultural background has the potential to enhance students' conceptual understanding [13]. For this reason we include the Hawaiian social studies standards. The History of the Hawaiian Kingdom Anchor Standards are broken up into inquiry standards well aligned with our project goals. Inquiry standards include SS.6-8.2.2 *(Gather relevant information from credible sources representing a wide range of views)*; SS.6-8.4.1 *(Construct arguments and explanations using claims and evidence from multiple sources while acknowledging the strengths and limitations of the arguments)*; SS.6-8.4.2 (*Present arguments and explanations using a variety of print and oral technologies [e.g., posters, essays, letters, debates, speeches, reports, maps] and digital technologies [e.g., Internet, social media, digital documentary]*); and SS.6-8.5.2 *(Examine the origins of a problem or issue and explain the challenges and opportunities faced by those trying to address it*).

Centering Indigenous Hawaiian experiences. In the first year, WMS students (n = 50) and their teachers (n = 2) will create local ethnographic narratives. Engaging their families, local businesses, scientists, community elders, and workers from across the island, students will explore the localized impacts of volcanic eruptions from factors such as vog (smog containing volcanic gasses) and lava flows. In this way, students will be considering both the Indigenous knowledge and the Western scientific knowledge related to volcanic eruptions. Students will develop an interview protocol and collect stories to showcase (1) what people should learn about their island's volcanoes, (2) community-driven questions around eruptions in terms of local impacts, such as vog and lava flows, (3) historical and traditional Hawaiian oral narratives, and (4) how a diverse set of jobs relies on knowledge of volcanic eruptions and technical skills related to computation, data visualizations, and simulations. Up to 10 students *who choose to participate* in the co-design process will meet with the RPP team during a summer co-design summit (see below) to share their knowledge and discuss the best ways to integrate their ethnographic narratives into the module. By sharing the Indigenous Hawaiians' knowledge and exploring the geologic history of the island, we hypothesize that students' sense of agency and educational relevance can be supported as they take on the role of culturally responsive science investigators.

Integrating oral history and volcano science. There are specific Hawaiian chants that begin with the word *Hulihia*, which means overturned, overthrown, and upheaved. These chants from somewhere between 800 and 1500 C.E., when the first people arrived in Hawai‘i, describe major volcanic activity of the islands [46]. The *Hulihia* chants include words for earthquake, moving lava, leaping fire, and diverse kinds of lava flows, the characteristics of fast- or slow-moving lava, clouds formed by steam or heat of the volcano, rising and falling land sections, extension of land and the weather impacted or produced by the eruptions [46, p. 143]. The details in one story, for example, reveal a remarkably accurate account of the two largest volcanic events to have taken place on the Big Island of Hawai‘i since human occupation.

Pele, goddess of fire, sent her sister Hi‘iaka to find her beloved Lohi‘au in exchange for a promise to spare Hi‘iaka's forest from fire and lava. Hi‘iaka agreed and, after overcoming many obstacles, brought Lohi‘au to Pele. Unfortunately, while Hi‘iaka was searching, Pele had grown frustrated and in a fit of anger burned down Hi‘iaka's forest. In revenge, Hi‘iaka took Lohi‘au for herself. Enraged at seeing them together, Pele killed Lohi‘au with an enormous eruption. Learning this, Hi‘iaka furiously dug into the volcano, sending rock flying everywhere until she eventually found Lohi‘au deep in the crater [10].

Using Carbon-14 to date past lava flows, scientists have found evidence of a long, intense eruption of Kīlauea around 1470 C.E. [47]. The lava flow covered 160 square miles, annihilating surrounding vegetation and land important to the early inhabitants [10]. Carbon-14 data and stratigraphic records also indicate the collapse of Kīlauea's caldera shortly after the large eruption. [47]. Stories of Hi‘iaka flinging rocks into the air as she searched for Lohi‘au's body align with the many smaller eruptions that a collapsing caldera would cause. This story and others derived from student ethnographic narratives will be used to provide context for exploration of volcanic eruptions.

In each activity, as part of co-designing the module, students will connect their ethnographic narratives to the learning goals of the activities and with the authentic computational practices of volcanologists. 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 into volcanic eruptions. Beginning with basic code blocks, students will use the *LavaCoder* to visualize single eruptions and explore one environmental factor at a time. The module and design of the computational model features will help students connect how the code is a representation of the mathematical lava flow equation, and that as they adjust the code, they are actively adjusting the variables of the equation. As students' code becomes more complex and contains more variables, they will begin to use common computational structures such as loop blocks and conditionals to examine how the relationships between variables within the lava flow system—viscosity, volume, and eruption rate—influence the spread of lava during an eruption. Students will analyze the visualizations derived from their experiments as evidence to understand the geologic system. As the students progress through the module, they will use code to create data visualizations of many simulated lava flows to use as evidence in understanding and communicating different eruption scenarios. In doing so, students will replicate the methods by which scientists use computational models to create volcanic eruption forecasts and learn how forecasts are used to develop warnings for upcoming eruptions. The progression through the activities means the sophistication of students' conceptual knowledge is built hand in hand with their computational abilities and is contextualized by the local setting and the ethnographic narratives. Finally, students will consider risk for their community by overlaying different maps on the simulated eruptions in order to identify the type and amount of land uses that could be affected (e.g., residential, farmland, commercial). In doing so, they will explore how assessing risk involves both the estimation of the likelihood of an event (lava flowing in or around their community) and considerations of impact that depend on the importance placed by the community on a place or object.

Research Plan

To ensure the effectiveness of the Pelehonuamea Project materials for the community at the center of this RPP, we employ a mixed methods Design-Based Implementation Research (DBIR) approach [48], [49]. Rather than communities being treated as consumers, DBIR requires collaboration across researchers and communities to develop "evidence-based improvements" [48] to classroom innovation. By inviting Indigenous Hawaiian students to be partners in the co-design of solutions rather than passive consumers of curricula, DBIR allows us to conduct research that is centered on the needs of communities. In this project, co-design serves as both a method of curriculum development and an intervention to develop and enhance students' sense of agency and educational relevance within STEM as well as their understanding of CS, CT, and geoscience. Accordingly, the research approach uses two parallel strands—first, to understand how partner students are affected by being active participants in the design process of the materials by creating ethnographic narratives and helping determine how to use them to contextualize module activities and second, to evaluate the effectiveness of the resulting module.

Methodological framework. We will employ the lens of Cultural-Historical Activity Theory, hereafter referred to as CHAT [50], [51] to understand and evaluate the project across cycles of design, implementation, and analysis. The intent of our DBIR process is to shape the module to maximize its utility and value for the participating Hawaiian teachers and students at WMS. Within a CHAT framework, we conceptualize learning as the co-construction of knowledge among learners, teachers, and scientists engaging with the tools and signs (i.e., language, gestures, inscriptions) that mediate learning within the school environment. Central to the CHAT framework is the idea that students deepen their engagement through *exchange* with their peers as members of both their classroom and broader *communities*. The Pelehonuamea Project focuses on students as both producers and consumers of curriculum in partnership with teachers and STEM professionals (Figure 2). Thus, this project manifests in two distinct but connected systems: the curriculum development activities that produce the ethnographic narratives and the classrooms implementing the module in which the ethnographic narratives contextualize the learning. Both center students' production of learning and academic achievement, and the valuing of these accomplishments.

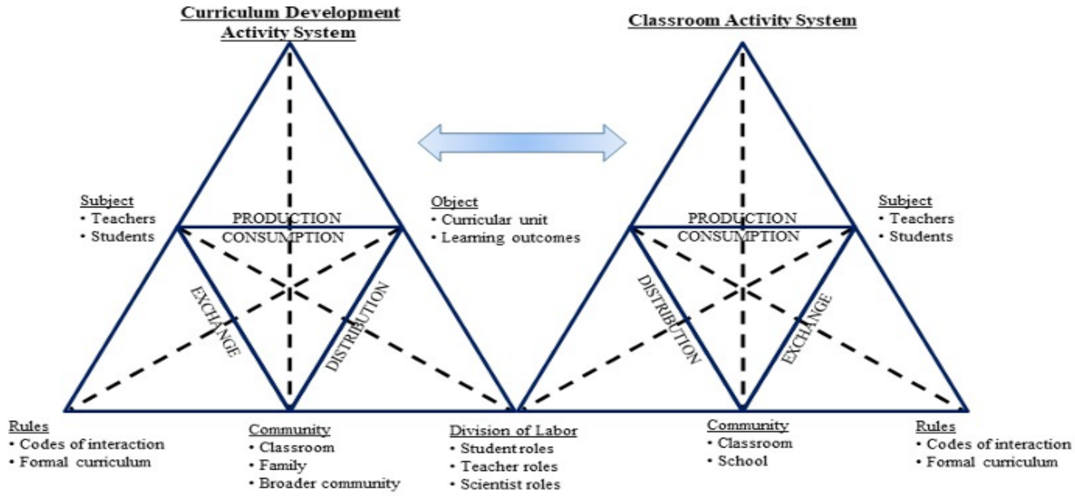


Figure 2. The CHAT activity framework withing observed classrooms. (Adapted from [51])

Historically, the role of students and their broader community (family, culture) is absent in curriculum development and thus has no impact on the material's role in classroom activity systems. As a result, exchange and distribution of student learning and achievement are limited to constrained and depersonalized materials. When students co-design materials, it allows them to represent their community within the curriculum and to manifest a new sense of agency and educational relevance that renegotiates all aspects of the schooling system [52], [53]. With students contributing to co-designing curricular materials, we intend to shift the customary means of production to student-driven culturally responsive, place-based STEM learning. These shifting elements of both the curriculum development and classroom activity systems in the framework will, we hypothesize, disrupt standard classroom norms and benefit all students by providing increased ownership and investment in the production of their learning outcomes and perspectives.

The DBIR Work Plan

Design Cycle 1: January 2025 to December 2025

Ethnographic study. Approximately 50 students at WMS will spearhead the youth-led ethnography effort to gather local stories and histories around volcanic eruptions. USU and WMS will work collaboratively to plan the multistep youth participatory ethnography process [54]. During the spring semester, students will conduct interviews of local elders, family members, scientists, and other community members. A subset of students (n = 5 to 10) who *choose* to work as partners will share ethnographies with USU and CC team members during RPP bi-monthly Zoom meetings.

Develop *LavaCoder*. Concurrent to the efforts on the Big Island, the CC team and the Hawaiian volcanologist consulting on the project will develop the *LavaCoder*. This design and development work involves creating the lava flow simulation and adding Hawaiian relief maps and street maps with clear topographic features and data about homes, businesses, farms, roads, and populations. Additional blocks and functions related to lava flow will be added along with specific supporting UI/UX features.

Hold a co-design summit. During the summer, the full RPP team plus the self-selected students will attend a week-long co-design summit in Hawaiʻi. Major activities during the summit include: (1) WMS students and teachers leading the effort regarding ethnographic narratives' emergent themes, issues, and histories and on using them to contextualize module activities, (2) pilot testing the *LavaCoder* and providing feedback to the CC team to inform refinement of the tool, and (3) developing an outline for the module. Central to this integration and curriculum design work, youth will engage in co-designing the articulation of how CS and CT are essential skills for everyone living on the island of Hawaiʻi.

Create module. From July through October, an online two-week module will be developed using CC's established authoring system. As the CC team drafts the module USU and WMS will support that effort with feedback and bi-monthly meetings to ensure that the module represents the stories and knowledge WMS students and teachers want centered. Additionally, the CGR assessment and two surveys will be adapted (see Data Collection and Analysis below). All completed materials will be reviewed by the Advisory Board, the external evaluator, and the volcanologist prior to implementation.

Design Cycle 2: January 2026 to August 2026

Pilot test module and instruments. Beginning in January, the module, assessment, and surveys will be tested with the students of the two WMS science teachers in their science classes (n = 50 students). The classrooms will be observed by a research assistant who is part of the WMS team. Observations will focus on the ways that new students engage with the contextualized ethnographic narratives and the computational volcanology investigations. Six student and two teacher interviews will be conducted after the implementation by the external evaluator. Student interviews will focus on their experiences with computational thinking and block-based programming and explore the effectiveness of the Hawaiian narratives for developing students' sense of agency and educational relevance. Teacher interviews will explore their experience with teaching with and about (1) coding, (2) computational models, (3) volcanic risks, and (4) a place-based module. Interviews and analysis of student work in the module, surveys, and assessments will inform revisions.

Revise module and instruments. In the spring after the implementation, we will revise the *LavaCoder,* module, surveys, and the assessment. WMS, CC, and USU will work together to incorporate the changes. We will also co-design teacher support resources. As CC team members draft the teacher materials, USU and WMS will support that effort with feedback and bi-monthly Zoom meetings to ensure that they are centered around the teachers' and students' needs. In addition, the RPP team will plan for a summer professional development workshop.

Provide a professional development workshop. In the summer, the project team will run a multi-session, professional development workshop for teachers in Hawaiʻi from two additional middle schools (n = 8, including 6 new teachers plus the 2 teachers from WMS) on the Big Island. Teachers from WMS and student partners from the previous implementation will be invited to lead sessions at the workshop. The workshop will focus on (1) science content and coding foundational to the module and (2) developing students' sense of agency and educational relevance as they familiarize themselves with the ethnographic narratives created by the student partners and incorporated in the module.

Design Cycle 3: September 2026 to December 2027

Field test module and instruments in additional middle schools. During the school year beginning in Year 2 and ending in Year 3, the 8 teachers (n = 400 students) who attended the summer professional development workshop will administer the pre-test and pre-surveys to their students, facilitate students' use of the module, and then administer the post-test and surveys. The members of the RPP team (researcher, graduate students, and the research assistant in Hawaiʻi will visit classrooms at each site to make observations according to a protocol developed based on the findings of the prior classroom observations. Specifically, we will record teacher-to-student, student-to-teacher, and student-to-student interactions in two realms: (1) learning related to CS, CT, and volcanic hazards and risks, and (2) students' sense of agency and educational relevance. We will pay special attention to how students react to the student-generated stories and how they engage with the *LavaCoder* while doing computationally mediated investigations.

Data analysis and dissemination. All data will be analyzed. Data collection, analysis, and dissemination efforts are described below.

Data Collection and Analysis

Qualitative data collection and analysis. In order to explore the extent to which project co-design activities develop students' sense of localized relevance and agency within science and STEM identities and how teachers respond to the classroom materials and activities, we will utilize observations and interviews with both students and teachers across all aspects of student participation in ethnographic narratives and for partner students participating in module development, as well as field notes of classroom processes and interviews of teachers and students.

Given the dual goals of developing a meaningful CS and CT geoscience curriculum and enhancing Indigenous Hawaiian students' sense of agency and engagement within the STEM context, it is necessary to attend to the dynamics of activity systems across the power structure inherent to classroom teaching and learning. For these reasons, we engage the analytic induction methodology [55], [56] to distill meaningful understandings of the varied perceptions, beliefs, and values of the members of the classroom community with attention to the CHAT mechanisms of production, consumption, exchange, and distribution. In this approach, data analysis extends beyond a straightforward constant comparison strategy [57] from which prospective themes emerge and accrete. Instead, our approach engages in a deliberate cyclical process of data coding to identify meaningful activities situated within and across categories of participants, interrogating the interpretations of those activities, and then returning to the data for possible disconfirming evidence. The students, teachers, and researchers at the co-design summit will discuss themes and meanings that emerge from the interpretations of the ethnographic narratives. By examining the interconnected experiences and beliefs of participants engaging in distinct ways and at different levels of involvement, we will elucidate the possible ways that those beliefs ultimately impact both student learning outcomes and development experiences.

Quantitative data collection and analysis. Quantitative measures include three instruments that students will complete prior to and after using the module: a computational geoscience reasoning (CGR) measure (see Results from Prior NSF Support), a survey of computational thinking skill development, and instruments to assess students' perception of agency and educational relevance in STEM.

The CGR instrument consists of 11 multiple-choice and 11 open-ended items loading on a single factor and addresses a set of integrated CS, CT, and scientific concepts that volcanologists need to follow when they use computational methods to assess risk [58](α = .851). In Year 1, the CGR instrument will be refined by situating the items in the community-specific and volcano-specific context and adding items related to community knowledge and local risks. The CGR will be piloted, refined, and then administered during the final classroom field test.

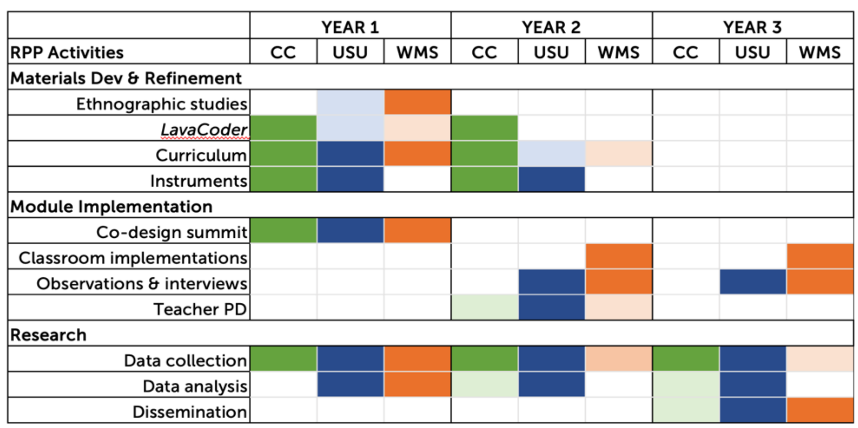
To measure the effects of locally relevant and culturally responsive computing learning experiences on middle school students' attitudes and understanding of CS and CT, we will analyze students' responses to a Computer Attitudes Survey (CAS) [13]; α =0.736) that measures students' (1) interest, (2) attitudes, and (3) understanding of computational concepts.

To assess students' perceptions of their educational agency and the relevance of the curriculum, several instruments will be used. The Becoming Effective Learners-Student Survey (BEL-S) classroom environment subscale will elicit students' perceptions of their teacher's ability to adapt to their learning needs and frame content in ways that relate to their lives, futures, and interests, as well as their willingness to empower students by intentionally eliciting their input on topics of instruction [59]. Additionally, we will elicit students' sense of empowerment within the classroom with the Learner Empowerment Scale [60], [61], which consists of three dimensions: meaningfulness (10 items), impact (16 items), and competence (9 items) with Likert-style responses. Factor analyses confirmed the three-factor structure, with each subscale demonstrating internal consistency $\alpha \geq 0.91$ [62]. Lastly, we will use the Frymier and Shulman [63] 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, attitude towards CS and CT, and sense of agency and educational relevance change over time. 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 pilot study these data will be collected only at WMS, so one-way MANOVAs will be used to assess pre-post change. 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.

Implementation analysis. We will interview teachers after module implementation to capture (1) their temporal reflections while implementing the module in their classrooms, and (2) their experiences of implementation and impressions of student success or struggle. We will focus interview questions on how engagement with the module may have shifted classroom dynamics with respect to the CHAT framework. For example, did engagement with the *LavaCoder* and the ethnographic narratives shift the normative patterns of how knowledge production work occurred in the classroom, or did inclusion of human impacts in the module change the ways in which students made connections between school learning and their communities outside the classroom?

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, (3) code used to create computational visualizations, and (4) model-based explanations. 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 and students' ability to connect ethnographic contexts to the learning. Following the pilot study we will look at all student responses to embedded assessments to guide revisions. Following the field test study embedded assessments will be analyzed in relationship to all pre- and post-measures described above. Figure 3 summarizes the DBIR timeline.



Dark color indicates lead for activity; if all are dark, work is equally distributed.

Figure 3. The Pelehonumea Project timeline highlighting the RPP activities.

Project Management

Amy Pallant (PI at the Concord Consortium) will direct the development of the *LavaCoder* and lead the co-design of the module and teacher support materials. She will also be responsible for the overall coordination of the co-design, research, and professional development work, as well as for the project budget. **Janice English** (Co-PI at Waimea Middle School) is the principal at WMS. She will manage teacher and student engagement with the co-design process and the data collection during the design studies. She will also manage instructional load assignments and will support the recruitment of two additional school sites. Ms. English has no prior NSF support as PI or Co-PI. **Colby Tofel-Grehl, Ph.D.** (Co-PI at Utah State University) will be responsible for data collection, analysis, and dissemination of qualitative data. As a former classroom teacher and leader of an eight-year RPP with WMS, Dr. Tofel-Grehl possesses the intersecting expertise to support youth and teachers in ethnographic research within their community. **David Feldon, Ph.D.** (Co-PI, USU), a national award-winning mixed methodologist with expertise on nesting students within teachers and schools will analyze student data.

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; 8/2016-9/2023).* **Summary of project results:** We developed the *GeoCoder*, a block-based programming workspace connected to a map or data-based visualization based on scientific equations used for research on volcanic and seismic hazards. We developed two online modules exploring tephra volcanic and seismic hazards, and a computational geoscience reasoning (CGR) measure to assess student understanding of coding, hazards, and risk. Students made significant pre- to post-test improvements in computational and geoscientific reasoning in the tephra 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 designed innovative technology-based opportunities to enrich both science learning and exposure to block-based programming and CT 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 CS and CT 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 CT to a different audience than traditional computer science classes. In the course of the GeoCode project, over 3,100 students used the seismic module and over 4,800 students used the tephra module in 14 states. The seismic module served as the basis for an ongoing ITEST grant (DRL-2241021) engaging diverse students in California in culturally relevant seismic investigations. **Publications:** [58], [64], [65], [66], [67], [68], [69], [70], [71]

CAREER: Job Embedded Education on Computational Thinking for Rural STEM Discipline Teachers (JEE) (*PI: Tofel-Grehl; DRL-1942500; $879,770; 2020-2025*). **Summary of project results:** JEE builds on prior work to validate a model of rural teacher professional learning that integrates STEM and computing content to support secondary student learning in locally relevant and geographically meaningful ways, including through 3D-modeled computational circuits of Hawaiʻi's volcanoes. Findings from this work indicate that Hawaiian youth desire locally relevant CS learning [16] and that teachers require lengthy structured support to engage CS/CT in core content classes [72]. **Intellectual merit:** The project targets rural teachers who receive little to no professional development (PD) to support effective computational thinking and computing engagement in their core instruction. The PD model allows rural teachers to learn with long-term support and scaffolds in place to both build their knowledge and the long-term capacity of the district and classrooms across the state of Hawaiʻi. **Broader impacts:** JEE meaningfully engaged 15 teachers and 400 students in a novel approach to integrating computing into science and engineering activities in communities across rural Hawaiʻi with a focus on Indigenous Hawaiian populations. **Publications:** [16], [72], [73], [74], [75]

Collaborative Research: Progressions of Skill Development in Biology Doctorates (*PI: Feldon; DGE-1431234; $1,151,431; 2014-2018; DGE-1760894; $2,459,199; 2018-2022*). **Summary of project results:** This study, which followed a national sample of 336 biology Ph.D. matriculants through graduate school and into postdoctoral employment examined skill development as a pervasive but poorly understood aspect of graduate education using a mixed methodological approach. In addition to focusing on cognitive aspects, the study integrated motivational and environmental factors, facilitating consideration of how they interact in the preparation of future scholars. **Intellectual merit:** Most studies of doctoral student development are "snapshot" investigations of individual reflection, interviews, or survey data. While valuable, these data are incomplete without longitudinal, triangulated investigations such as this one. Research skill development may be more completely understood when studied in its natural habitat and over the length of its natural tenure. **Broader impacts:** This project has generated rigorous empirical findings that have informed and reformed educational practice of research skill development in the biological sciences. Identification of normative patterns of skill development can be used to improve graduate training and possibly accelerate skill development through curricular and co-curricular experiences designed to support and advance research skills in the biological sciences. **Publications:** [76], [77], [78], [79], [80]

Evaluation

Evaluation of the project will draw from "Indicators of research-practice partnership health and effectiveness: Updating the five dimensions framework" [81]. As this is a fairly mature RPP the evaluation will 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*). An external evaluator, **Dr. James Peugh,** will collect and analyze evaluation data in both quantitative and qualitative formats. Dr. Peugh has expertise in statistical analyses involving high rates of missing data and nested data structures, as well as training in qualitative research methods. To evaluate the RPP specifically, a mixed methods approach will be used and include qualitative interviews supplemented with quantitative data based on the tools developed for Dimensions 2 and 4 of the framework, such as surveys, reflection prompts, and ongoing discussions with the team throughout the DBIR cycles.

Additionally, a grounded-theory approach will be used to better understand teachers (n = 2 interviews in Year 2, 8 in Year 3) and students (n = 10-12 interviews across three years). Structured interview questions will explore what aspects of the project best facilitated student knowledge, engagement, and attitudes and what types of support measures or resources could be added or implemented to improve students' experiences. All interviews will be transcribed and coded using a constant comparison approach to identify emergent and consistent themes.

Quantitative data will be obtained in the form of survey data. Surveys will assess teachers' coding and computational thinking capabilities and strategies (Computational Thinking Test [CTt]; [82]) and their self-efficacy and outcome expectations related to teaching with culturally responsive and place-based curriculum (Culturally Responsive Teaching Scales [CRTS]; [83]). The CTt consists of 28 multiple-choice items, which assess the following concepts: (1) basic directions and sequences, (2) loop-repeat times, (3) loop-repeat until, (4) if-simple conditional, (5) if/else-complex conditional, (6) while conditional, and (7) simple functions. In addition, one of the following three cognitive tasks are required for solving each item: (1) sequencing, (2) completion, and (3) debugging. Scale reliability assessed across a wide age range yielded internal consistency of $\alpha = 0.762$ [82]. CRTS ([83], [84]; $\alpha \geq 0.94$) will be used to assess beliefs related to practices that promote student agency and perceived educational relevance. Items have teachers estimate their ability to implement and the outcomes they expect from pedagogical practices intended to build trust, adapt curriculum and pedagogy to be relevant to their students, foster a supportive learning environment, and empower students to connect learning their lives. Survey analyses will be conducted at the factor and item levels with proper analysis specifications (e.g., response-variable log-transformation and robust [MLR] maximum likelihood estimation) to adjust for non-normally distributed responses and properly handle any missing data, respectively. Effect sizes (*Hedges g* for correlated comparisons) will be computed for each item-level analysis and $g \geq 0.40$ will be considered noteworthy; statistical significance at the sample sizes expected is unrealistic due to low statistical power.

A second level of evaluation will take place via a three-member Advisory Board (AB), which will convene via Zoom twice per year over the first two years. They will provide feedback on the module content, the *LavaCoder*, and the inclusion of the student ethnographic studies, the research instruments, collected data, and interpretation of results. Recommendations will be addressed during the revision process. AB members are: **Debbie Fields**, an associate research professor of Instructional Technology and Learning Sciences at Utah State University, who researches learners' creative expression with digital media, coding, and everyday craft materials; **Mark Guzdial**, a professor of electrical engineering and computer science at the University of Michigan, with expertise in computing education research, task-specific programming languages, and the learning sciences; and **Christopher Rothschild**, an educator and researcher and project director for the Hālau Hekili Project at Windward Community with over 15 years of experience working with global communities to understand technology and information behaviors to support locally driven and designed programs.

Dissemination

The *LavaCoder*, module, assessments, surveys, and teacher training resources will be made freely available on CC's STEM Resource Finder. The release of the materials will be accompanied by announcements and blog posts to communities of interest—both Hawaiian schools and schools across the country. The team will also disseminate work beyond academia. To enhance local impact, findings will be disseminated through presentations to administrators at the district and state levels through WMS and the Hawaiʻi Board of Education. Findings will also be shared at the local Kamehameha School meetings and community partner meetings. Students alongside partners will present at conferences such as the Hawaiʻi International Conference on Education (HICE), the ACM International Computing Education Research (ICER) conference, the American Educational Research Association (AERA) conference, the International Conference for Learning Sciences (ICLS), and the Indigenous Education Research Conference. Scholarly findings will be published in journals such as *Theory & Practice in Rural Education, the Journal of Multicultural Affairs, the Journal of Learning Sciences*, and *the American Educational Research Journal.* Dissemination to practitioner audiences will include presentations at SIGCSE and the World Indigenous Peoples Conference on Education, as well as publication in *Science Scope, Learning for Justice,* and *Rethinking Schools*. Finally, we will disseminate our findings through social media and the *@Concord* biannual newsletter, distributed for free to over 63,000 digital and print subscribers.

Broader Impacts

The project's broader impacts will be established in three areas. First, we will work directly with 8 middle school teachers and 400 students. We will prepare teachers to engage in culturally responsive science and computer science pedagogy that supports CS and CT for all students in Hawaiʻi middle schools. Over the course of their careers, the teachers trained to use the *LavaCoder* and the module will teach thousands of students, and their ability to incorporate computing into their core content instruction can transform the shape and breadth of computation embedded in STEM learning for their communities. Second, we will help districts meet the educational goals established by the Hawaiʻi Department of Education that are currently unmet. By embedding CS within Earth science core content areas and integrating authentic science experiences with students' cultural worldviews and experiences, the materials are specifically designed to provide a context that appeals to the broadest range of Indigenous Hawaiian students. As such, the module, *LavaCoder*, and teaching resources can scale beyond the participating schools to other middle schools in the state. Third, by conducting research on the co-design process, the Pelehonuamea Project can inform models of effective engagement with students from communities that have historically been nondominant in Western science. The transformative potential of the locally contextualized materials can offer a model of the ways in which historically marginalized youth can develop a sense of agency and educational relevance during the design process.