National Earth Science Teachers Association

THE EARTH SCIENTIST

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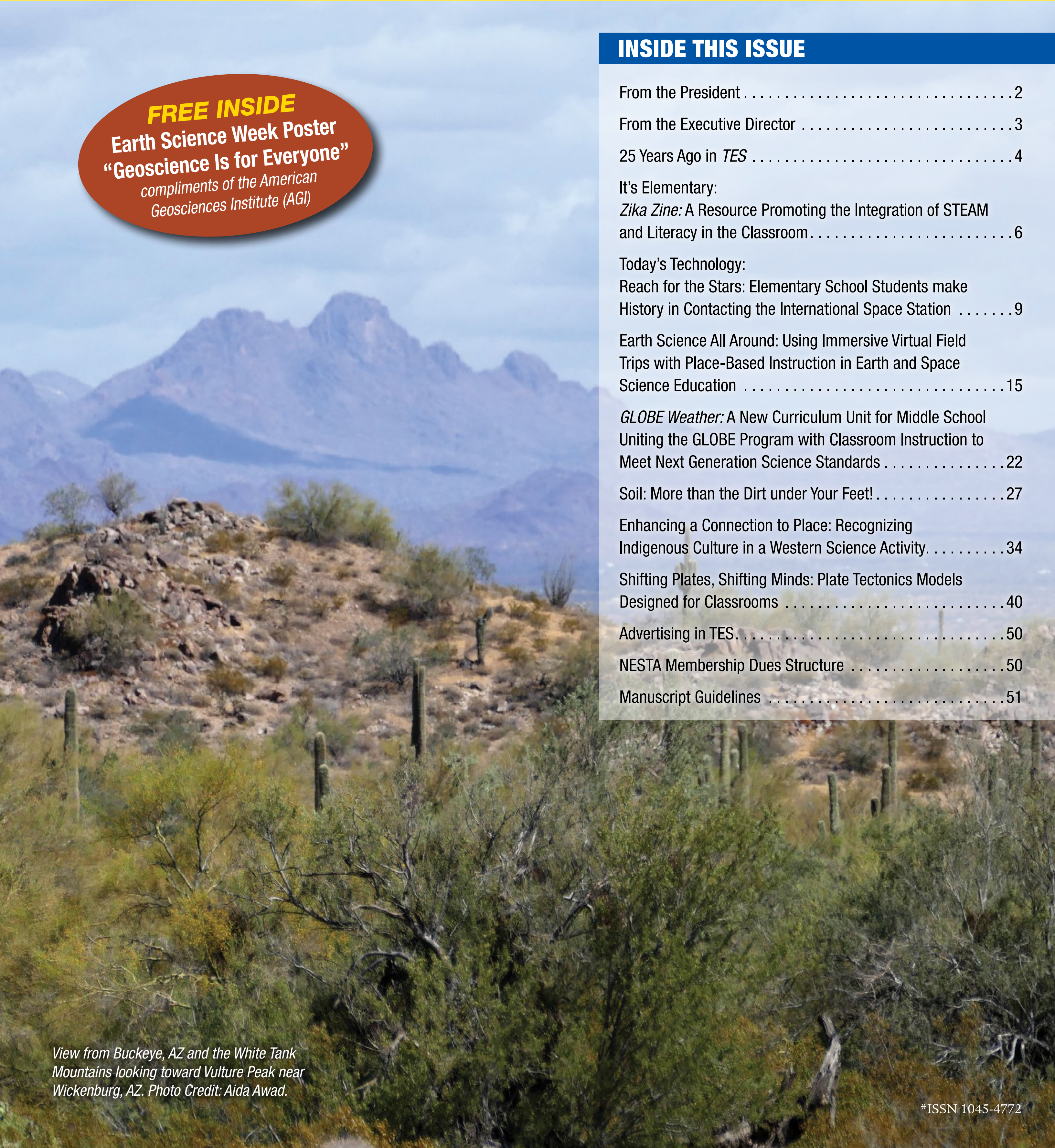

FREE INSIDE
Earth Science Week Poster
"Geoscience Is for Everyone"
compliments of the American Geosciences Institute (AGI)

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View from Buckeye, AZ and the White Tank Mountains looking toward Vulture Peak near Wickenburg, AZ. Photo Credit: Aida Awad.

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NESTA'S MISSION

To facilitate and advance excellence in Earth and Space Science education.

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From the President

Seasons of Change

Greetings NESTA colleagues,

Happy Spring and good tidings on this, my final President's message. Spring is commonly referred to as a season of renewal, growth, and change, and here at the end of my two years as President, this sentiment especially rings true. At a time when organizations must change or risk permanent stagnation, NESTA has stepped forth and allowed for new ideas and ventures to be seeded and take root. During this time, NESTA has continued to evolve, bringing our message to more Earth Science education advocates through multiple avenues as we have expanded our media and web presence through the diligent work of our social media curators, web coordinators, and committee leadership. We have continued to provide educators with timely professional development through national and area NSTA conferences, GSA, and AGU, but we have also strengthened partnerships and collaborated on additional means of sharing ideas through joint webinars and specialty presentations and outreach. We have developed a tagline and are currently working to revitalize our Mission and Vision to better represent and equip our organization and its members with a focus on the future.

As a leader, I have certainly evolved through the duration of my tenure. I have grown exponentially through collaboration with my fellow Executive committee leadership, Board of Directors members and also through opportunities for involvement with fellow Earth Science education organizations and their leaders. I have been blessed to have the wise counsel of longtime NESTA leaders and am grateful for their assistance in navigating the role of President.

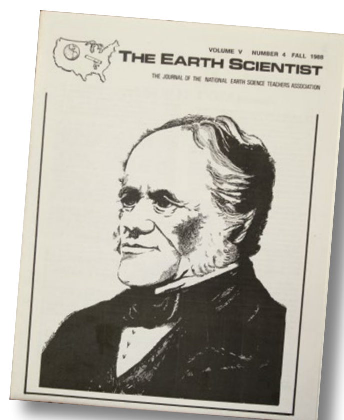
As a new season of NESTA leadership begins, I am excited for what that change will bring: fresh perspectives from our newly appointed and elected leaders, both those who have never served in a leadership role and those whose role may have shifted to another role; new ideas for serving our teachers in the classroom so that they may equip their students, our future Earth and Space scientists and stewards of our planet; and finally, a revitalized hope that we as an organization can grow and adapt in an ever-changing world, continuing to lead the charge for a better Earth Science citizenry as we work to promote our **One Earth. Our Future.**

Cheers,
Belinda Jacobs
NESTA President 2018-2020

From the Executive Director

This long overdue issue has been delayed by COVID-19 and other factors but is here now. Its theme, taken from the 2019 AGI Earth Science Week theme is "Geoscience is for Everyone!" A lot has happened over the past year that makes this issue even more relevant. Two articles in this issue celebrate diversity, one by championing low-income, elementary students connecting with an astronaut on the International Space Station and another by incorporating Indigenous knowledge and ideology into an activity centered around revitalizing salmonid populations. Many of the resources shared in this issue lend themselves to remote teaching and learning. These include: teaching via virtual fieldtrips; mobile apps like the Mosquito Habitat Mapper on the GLOBE Observer app; using a zine to help students understand Zika, a mosquito-borne disease; a free online curriculum on weather from GLOBE; free online simulations and curriculum materials around plate tectonics from the GEODE project; and resources around soils, more than the dirt beneath our feet. There is a synergy with these remote resources as many of them also make science more accessible, which in turn supports the idea that *Geoscience is indeed for Everyone*. And now a transition.....

In the fall of 1988, I was assigned to teach high school Earth science (along with biology) in Las Vegas, Nevada. Having no background in the subject, I immediately signed up for courses at the local university and felt compelled to find a professional society to help me. I joined NESTA. The first issue I received of the journal, *The Earth Scientist*, (TES) had Charles Lyell on the cover and contained interesting articles, classroom ideas, and teaching resources. My 32-year-old paper copy has held up well through the years as has TES over time. TES has a dedicated editor now (hurray!), Peg Steffen, who I am certain will continue to carry on its quality legacy.



Thirty-two years ago, I never could have imagined that I might one day serve as NESTA's Executive Director. It has been an honor to have served you from 2015 to 2020. However, my time as Executive Director has ended. Just like with Belinda, there are those who have mentored me in the organization that I will always remember fondly. Most of all I will remember the many relationships I formed with those of you I met at conferences, webinars, workshops, and other outreach venues. I expect to see you again, virtually for now, but hopefully in person when these crazy times come to an end. Wishing the best to all of you.

Sincerely,
Dr. Carla McAuliffe
NESTA Executive Director, 2015-2020

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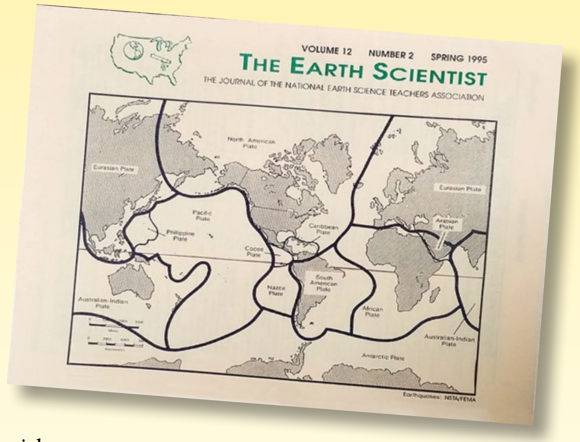
25 Years Ago in TES



Twenty-Five years ago, in 1995, TES was in its twelfth year of publication. The focus of this Spring issue was “Plate Tectonics”, and fittingly, the cover of the Spring issue featured a map of the earth with the plate margins plainly marked. This issue led off with an in depth, 10 page article detailing the latest information about the Plate Tectonics. The next article dealt with a survey ship, the “Tectonica”, which measured the polarity of ocean floor volcanic rocks. This was followed by an article describing an activity in which the students try to reassemble Pangea. There was an article which was a narrative of an earthquake in Japan, and how it was experienced in Hawaii. Finally, there was an article detailing an Earthquake plotting activity, and how the “new” internet will soon impact the availability of data.

By Tom Ervin

EARTH SCIENCE WEEK

Every Week is Earth Science Week!

In this issue you will find a copy of the poster celebrating AGI's 2019 Earth Science Week which is held mid-October each year. The theme was "Geoscience is for Everyone" which emphasizes diversity, equity, and inclusion, plus the importance of the geosciences in the lives of all people.

The Earth Scientist

The Earth Scientist is the journal of the National Earth Science Teachers Association (NESTA). It is published quarterly (January, March, June, September) and distributed to NESTA members.

To become a member of NESTA visit nestanet.org.

To get more information about NESTA or advertising in our publications, contact, Peg.Steffen@gmail.com.

DESIGN/LAYOUT
Patty Schuster, Page Designs

Zika Zine: A Resource Promoting the Integration of STEAM and Literacy in the Classroom

Rusty Low, Senior Scientist, Institute for Global Environmental Strategies

O*pportunity, motivation* and *enthusiasm* are all key to science learning and retention in students. You may not realize it, but you have an *opportunity* for students to experience firsthand the practices of science right in your schoolyard or their backyards by making and reporting mosquito observations. And talk about *motivation*! Students who report their data using the Mosquito Habitat Mapper on the GLOBE Observer mobile app are actively protecting themselves and their friends not only from nuisance mosquito bites, but also from potentially serious diseases that are transmitted by mosquitoes. The science that they are doing has immediate, real life importance. And while you may not find it easy to convey your *enthusiasm* about mosquito research, the newly released *Zika Zine* will do that for you!

In *Zika Zine*, students are introduced to Wanda, Hester and Maurice, three tiny mosquitoes with big personalities whose adventures explain mosquito biology, NASA science and how to prevent mosquito-borne disease. In the 9-panel storyline, students find out why female mosquitoes bite and how their bites can unintentionally transmit disease. Two of the protagonists, Hester and Maurice, see a student using the Mosquito Habitat Mapper on the GLOBE Observer mobile app to document and report immature mosquito larvae in a discarded tire: standing water is where mom mosquitoes lay their eggs (**Figure 1**). While reading about Hester, Maurice and Wanda's adventures, students learn about the role both citizen scientists like themselves and NASA satellite data play in helping scientists to predict future disease outbreaks, saving thousands of lives.

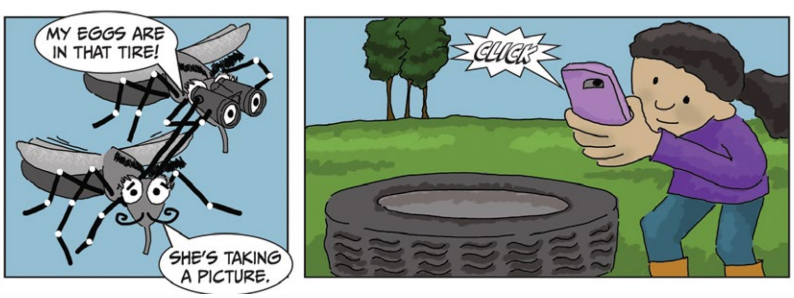


Figure 1. In *Zika Zine*, a citizen scientist takes a picture of a mosquito habitat. © 2019 University Corporation for Atmospheric Research. All rights reserved.

After reading the zine, students can go outside and document mosquito habitats using Mosquito Habitat Mapper on the GLOBE Observer app. The GLOBE Observer mobile app is available at no cost in app stores. The Mosquito Habitat Mapper records the date, time and location of sampling automatically, and students identify the type of mosquito habitat they found and how many immature mosquitoes (larvae) they see in the water.

With simple water sampling equipment, such as a cup or turkey baster, young citizen scientists can take a specimen back to the classroom and look at it under a microscope. In the time of COVID-19, if you are teaching virtually, students can also use the zoom function in a phone to see the specimen more clearly or use an inexpensive 60x-100x clip-on microscope to identify morphological features. Students take an image and can share it with classmates in addition to uploading it to Mosquito Habitat Mapper on the GLOBE Observer app. Using the built-in key in the app, students can determine whether the larval specimen is a kind of mosquito that could grow up to be a disease vector. **Note:** It is important to be aware that mosquito larvae are safe for students to observe, they do not bite and cannot transmit disease.

Table 1. Grade 5 NGSS Earth and Human Activity performance expectation, science and engineering practice, disciplinary core idea, and cross-cutting concept congruent with *Zika Zine*

Performance Expectation
5-ESS3-1. Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment.
Science and Engineering Practices
• Obtain and combine information from books and/or other reliable media to explain phenomena or solutions to a design problem.
Disciplinary Core Idea
• **ESS3.C. Human Impacts on Earth Systems**. Human activities in agriculture, industry, and everyday life have had major effects on the land, vegetation, streams, ocean, air, and even outer space. But individuals and communities are doing things to help protect Earth's resources and environments.
Cross-Cutting Concepts
• **Systems and System Models.** A system can be described in terms of its components and their interactions.

You might wonder how the study of mosquitoes fits in your Earth science classroom, but the connections are powerful (**Table 1**). In addition, GeoHealth is rapidly emerging as a transdisciplinary area of scientific research that connects human health, GIS and Earth system processes. Both mosquito population dynamics and vector-borne disease outbreaks respond to changes in environmental conditions such as temperature, precipitation and land cover, so both weather and extreme Earth events can be connected to mosquito science.

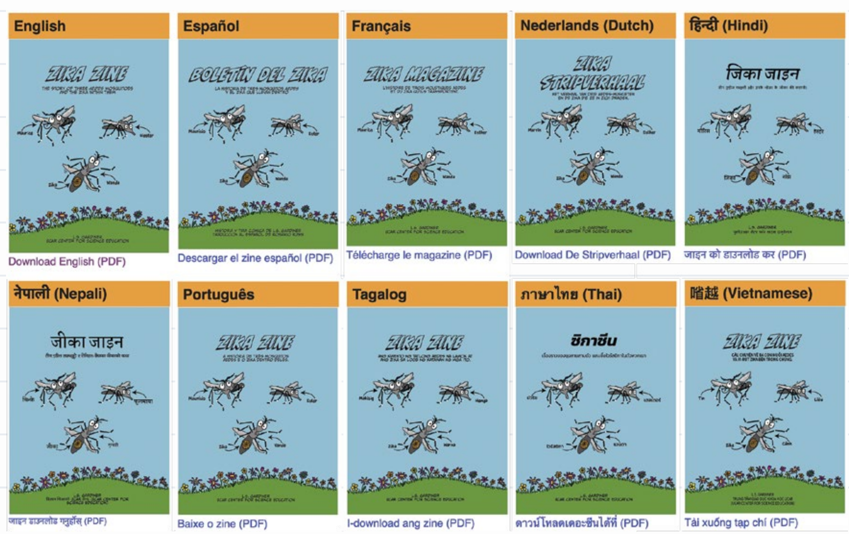


Figure 2. *Zika Zine* is available for download in 10 languages.

Zika Zine is freely available as PDFs online at scied.ucar.edu/zikazine (**Figure 2**). You can connect your science investigations to art through two STEAM activities that support *Zika Zine: How to Draw Wanda:* scied.ucar.edu/sites/default/files/images/video/drawwanda.pdf, and *Make your Own Comic:* scied.ucar.edu/sites/default/files/images/video/myzinecomic.pdf.

Zika Zine is authored by artist and scientist Dr. Lisa Gardiner, UCAR Center for Science Education and was produced in conjunction with the project, *Engaging Citizens in the Forecasting and Observation of Mosquito Threats*, an initiative of the GLOBE Implementation office funded by the U.S. Department of State.

Online resources for teaching about mosquitoes

Mission Mosquito Investigation Notebook

strategies.org/products/mosquito-investigation-notebook/

Using guided explorations, this resource introduces using scientific notebooks to collect observations and ask questions. It also includes discussion questions, further readings, and a companion guide for parents.

Mosquito Habitats and Hideouts

strategies.org/products/mosquito-habitats-and-hideouts/

This game can be played three different ways: Bingo, Name That Habitat, or Sketch That Habitat. Players learn about the variety of mosquito habitats, hideouts, and life cycle stages.

Mosquito Tellers

strategies.org/products/mosquito-tellers/

Taking inspiration from the popular children's fortune teller game, the Mosquito Tellers familiarize the players with the scientific concepts related to mosquito biology, prevention and protection, and diseases. A blank teller is included to write your own mosquito questions.

Get the app: observer.globe.gov/about/get-the-app

Get started: observer.globe.gov/do-globe-observer

About the Author

Rusty Low, Ph.D., is a senior scientist at the Institute for Global Environmental Strategies, Arlington VA, and the science lead for the NASA GLOBE Observer Mosquito Habitat Mapper citizen science app. She works at the forefront of citizen science and its application to combat vector-borne disease such as Zika. Working through NASA, NSF and USAID projects in the U.S. and overseas, she is demonstrating how educators, students, public health officials, citizens and even space scientists can work together to identify mosquito habitats and develop critical mitigation strategies to reduce outbreaks of mosquito-borne diseases. Find out more about the NASA GLOBE Observer app, the GLOBE Mission Mosquito campaign, and associated classroom activities and resources at these websites:

observer.globe.gov

globe.gov/web/mission-mosquito

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TODAY'S TECHNOLOGY

Reach for the Stars: Elementary School Students make History in Contacting the International Space Station

Rita Barakat, USC Neuroscience Graduate Program, Joint Educational Project Young Scientists Program
Dieuwertje Kast, USC Rossier School of Education, Joint Educational Project Young Scientists Program

Abstract

The USC Young Scientists Program (YSP), local Los Angeles Ham Radio Technicians, and educators, staff and students at Vermont Avenue Elementary School were selected to host an Amateur Radio on the International Space Station (ARISS) contact, which took place on Monday, October 28th, 2019. The contact presented an extraordinary opportunity for students to learn about life and research on the International Space Station (ISS) and to speak to an astronaut on the International Space Station (ISS). The event held special significance for the community, being the first ever K-5 ARISS contact for the Los Angeles Unified School District (LAUSD). In addition to participating in an adapted ISS-ABOVE curriculum, students played a critical role in ensuring that the contact went smoothly, and we celebrated the students' new knowledge and enthusiasm about space. An internal competition was conducted to decide the ten student finalists who would ask their questions directly to the astronaut during the window designated for the contact. From the students' post-contact reflections, it is clear that the efforts that went into making this opportunity possible had a profoundly positive impact on students' perception of themselves as young scientists and inspired the community at large to be more involved in augmenting students' science education.

> **Rita Barakat:** "This is KN6CHS, do you read me? Over."
>
> **Luca Parmitano:** "Yes, I read you loud and clear. Over."

Introduction

This was the beginning of a live exchange between elementary school students and an astronaut on the International Space Station. After over a year of proposal-drafting, internal preparations and establishing partnerships with licensed ham radio technicians in the Los Angeles area, underrepresented minority students at Vermont Avenue Elementary School, in partnership with the University of Southern California's Young Scientists Program (YSP), became the first K-5 students in the Los Angeles Unified School District (LAUSD) to participate in an ARISS radio contact event. Amateur Radio on the International Space Station (ARISS) is a volunteer organization that recruits licensed amateur radio technicians and pairs them with educators to schedule designated times and dates with NASA for initiating radio contact with the International Space Station (ISS).[1] ARISS partners directly with NASA to make these contacts possible, and due to the incredibly packed schedule of the crew members on the ISS, only 15 contacts across the world occur in a calendar year, making such contact slots highly coveted and prestigious.[1]

The Live Contact

As per the recommendations and encouragement of the assigned ARISS mentors, YSP ensured that the entire school body was involved with this live contact with an astronaut, thus giving students agency and authority in their own unique learning experience. A space/ International Space Station themed curriculum was developed by YSP Program Assistants to prepare students for the contact event, and guest lectures and demonstrations from field experts including Liam Kennedy (Developer of the ISS Above) and Darrell Warren (ARISS Educational Mentor and retired LAUSD educator) gave students a valuable opportunity to interface with the technology used to track and communicate with the International Space Station.

The contact was hosted through a school-wide assembly, and kindergarten through second grade students contributed significantly to the artistic decorations and organization of the auditorium leading up to the contact event. YSP also established a partnership with the USC Annenberg Media and Annenberg Student Representative Joshua Chang assisted with setting up a livestream for the event in order to accommodate students, LAUSD educators and administrators, as well as community members who, due to the maximum occupancy of the school's auditorium, were unable to be physically present at the contact event. This livestream was then uploaded to YouTube and available for broader dissemination to press, media and other parties around the world following the contact event.

Figure 1. The final 10 Vermont Elementary School students who were selected to ask Italian Astronaut and ISS Commander Luca Parmitano questions about life and science in space.

To select which students would have the opportunity to speak directly with the astronaut during the contact event, YSP facilitated a question competition at the school in the early Fall of 2019, with the assistance of Vermont Elementary School teachers and the leadership

Table 1. The 10 student finalists' questions for Astronaut and ISS Commander Luca Parmitano. Students were instructed to come up with questions that were thoughtful, meaningful to them personally, and not easily searchable.

Vermont Elementary School Student Finalist Questions

Damarion (Age 10)	*"How long does it take to get back to Earth?"*	Damarion (Age 10)	*"How do you sleep, and in what do you sleep?"*
Melody (Age 10)	*"What encouraged you to be a scientist?"*	Melody (Age 10)	*"When you were young, did you want to be an astronaut?"*
Savannah (Age 8)	*"How does it feel to be in space?"*	Savannah (Age 8)	*"How did you become an astronaut?"*
Isaac (Age 8)	*"What do you do in space when there's danger?"*	Isaac (Age 8)	*"What do you do when you take a break in space?"*
Heidi (Age 9)	*"Do you celebrate any holidays up in space?"*	Heidi (Age 9)	*"Can you do your work in space without your work floating away?"*
Jayden (Age 9)	*"What did you study when you were growing up?"*	Jayden (Age 9)	*"Who would you thank for helping you to accomplish your dreams?"*
Melanie (Age 9)	*"What do you need to be worried or alert about when on a spaceship?"*	Melanie (Age 9)	*"How do you get ready to go into space?"*
Andrew (Age 10)	*"What are the most important jobs in the space station?"*	Andrew (Age 10)	*"How is it that you guys get your food supply?"*
Nickolas (Age 10)	*"Do the astronauts at the ISS get older faster or slower, or is aging the same?"*	Nickolas (Age 10)	*"Is it dangerous to flip upside down after you are finished eating?"*
Aundrea (Age 10)	*"How do you communicate with your family, and do you ever miss them?"*	Aundrea (Age 10)	*"How did you feel saying goodbye to your family and boarding the space station?"*

staff of YSP. Questions for the ISS crew member were evaluated based on their thoughtfulness and creativity as well as their "not easily Google-able" nature.

Throughout the process, YSP aimed to give all 300 of the students at the school a voice so that they would be able to propose their own unique questions to the astronaut. All of the questions that were submitted were displayed in the form of a collage on the walls of the auditorium. These questions went to a panel of judges and the top 10 questions winners (**Figure 1**) were selected to ask their questions directly to astronaut and ISS Commander Luca Parmitano (from the Italian crew on-board the ISS Expedition 60) during a tight, approximately 9-minute contact window in the early afternoon of Monday, October 28, 2019. The final student questions that were read aloud during the contact event are summarized in **Table 1.**

The contact period itself was limited by the angle at which the ISS was due to pass over the elementary school on that particular date. Directional and radial antennas installed on the roof of a building just outside the multipurpose room (pictured in **Figure 2**) at the school allowed for precise tracking of the space station during this contact period. The Ham Radio Team that YSP partnered with included: (Bob Koepke (AA6TB), Ron Grassl (AG6ST), Norm Thorn (K6UU), Darrell Warren (KA6OSC) and Brian Johnson (AB6UI), whose collective radio expertise and equipment made this event possible.

Date	Time Window	Angle
Monday, 10/28/19	11:57:35 am - 12:08:23 pm (PST)	70°
Tuesday, 10/29/19	11:09:05 - 11:19:40 am (PST)	36°
Wednesday, 10/30/19	11:57:15 am - 12:07:38 pm (PST)	31°
Thursday, 10/31/19	11:08:34 - 11:19:20 am (PST)	64°
Friday, 11/1/19	10:19:59 - 10:30:47 am (PST)	62°

Figure 2. (Top Left photo) Amateur (Ham) Radio Team Members installing the primary antenna and two back-up antennas on the roof above the Multipurpose Room at Vermont Elementary School. From left: Ron Grassl, Brian Johnson, and Bob Koepke. (Top Right photo) YSP TAs Marisa Nives (left) and Rita Barakat (right) standing proudly in front of the primary Yagi antenna. (Left table) The original list of possible direct contact dates, times and the angles at which the ISS would be passing over the coordinates of Vermont Avenue Elementary School for each possible time window. YSP ranked these options in terms of priority and were ultimately assigned the highlighted time window to make a direct contact.

In addition to being part of a truly historic event for the school district and the community more broadly, students participated in a modified version of the ISS ABOVE curriculum, established by ISS ABOVE creator Liam Kennedy in collaboration with DJ Kast and Rita Barakat. Students learned about the various interstellar forces that act upon our planet and other celestial bodies in our solar system, as well as the kinds of research projects scientists conduct on-board the space station.[3] Next Generation Science Standards that correspond with some of the lessons from the curriculum are shown in **Table 2**.

Table 2. Next Generation Science Standards (NGSS)[4] that correspond with some of the YSP-ISS ABOVE lessons from the adapted curriculum third through fifth grade students at Vermont Elementary School participated in as part of their preparation for the ARISS Contact Event.

1-ESS1 Earth's Place in the Universe

ARISS Contact with Astronauts on the International Space Station

Performance Expectations/ NGSS Standards

1-ESS1-1. Use observations of the sun, moon, and stars to describe patterns that can be predicted. [Clarification Statement: Examples of patterns could include that the sun and moon appear to rise in one part of the sky, move across the sky, and set; and stars other than our sun are visible at night but not during the day.] [Assessment Boundary: Assessment of star patterns is limited to stars being seen at night and not during the day.]

Science and Engineering Practices

Planning and Carrying Out Investigations)

- Students created their own questions to ask the astronaut to investigate more about life onboard the International Space Station

Analyzing and Interpreting Data

- The chosen questions were asked to the astronauts live and students were able to collect observational data about life onboard the space station.
- The space themed curriculum that was introduced before the contact allowed students to learn about orbits and how they parallel how the ISS is orbiting the Earth

Disciplinary Core Idea

ESS1.A: The Universe and its Stars. Patterns of the motion of the sun, moon, and stars in the sky can be observed, described, and predicted.

- Students learn about the patterns of motion of the International Space Station.
- The orbit of the moon is similar to the International Space Station The patterns can be observed and described with the ISS above device and with the naked eye as the ISS goes across the sky at night.

Cross-Cutting Concepts

Patterns in the natural world can be observed, used to describe phenomena, and used as evidence. (ESS1-1), (ESS1-2)

- The International Space Station has patterns in its own motion around the planet and for the lives of the astronauts live onboard. Students learn how these patterns represent different scientific space themed phenomena like orbits and gravity

Figure 3.

(Top left) 3rd grade students at Vermont Elementary School learn what it takes to set a table for dinner on the International Space Station!

(Top right) A 4th grade student plots the orbital path of the International Space Station on the surface of an orange, to understand how mercator (flat) maps are generated.

(Bottom left) Liam Kennedy (center), the developer of the ISS-ABOVE, with students from Ms. Campos' 4th grade class.

(Bottom right) Display of the ISS-ABOVE in the library at Vermont Elementary School.

Students also engaged in hands-on, inquiry-based science activities (some images of which are shown in **Figure 3**) that focused on specific aspects of life in space, including how to eat and sleep in a microgravity environment such as that on the space station.

Immediately after the contact event, fourth grade teacher Ms. Campos commented that "one of my students turned around, looked at me and said 'We really talked to a real astronaut! Wow!' The look on his face: absolutely priceless." Fourth grade student Jayden B. was one of the selected question winners, and asked the ISS Commander Parmitano who he would thank for helping him to accomplish his dream of going into space. At the end of his detailed response, Luca added, "I really thank everybody, including you for your questions."

In the days immediately following the contact, fourth grade students in Ms. Doreza's class recorded their thoughts and feelings from the contact, as well as reflected on their own learning through the experience. Arlette Garcia called the contact the "best day of my life!" and expressed overwhelming pride at being part of such a historic event for her school, a sentiment that is clear in the other 25 students' reflections. Another student from the class, Amber Chicas, pointed out how "amazing" it was that the "ham radio could reach Luca all the way up in space", while her classmate Darlene Martinez felt "inspired" to "learn more about space and astronauts" as a result of the contact experience. Perhaps most endearing and meaningful to the ham radio technicians that made the contact possible, Miguel Petz noted the elegant simplicity of salutations in ham radio "speak", including how to say "goodbye in numbers (73)". Because the ARISS contact required an interdisciplinary approach to preparing the students (focusing not just on the space/ astrophysical science pertaining to the ISS, but also the ham radio technology and background necessary to make contact with the space station), many students expressed a broad interest in radio engineering and space travel from their experience participating in the contact.

The Young Scientists Program Description

The Young Scientists Program (YSP) is an inquiry-based, hands-on Science, Technology, Engineering, Arts and Math (STEAM) educational outreach program operated by the USC Joint Educational Project (JEP). The program aims to address a critical lack of science education in JEP partner schools by recruiting STEAM undergraduate and graduate students to serve as Teaching Assistants (TAs) who, under the direction of the JEP STEM Programs Manager and individual YSP Site Coordinators, bring scientific laboratory experiences directly to students and their teachers.

YSP targets students that are considered economically-disenfranchised and racially and ethnically underrepresented in the health-related sciences, including African Americans, and Latinx populations. The racial demographics of the students that participate in the program are approximately 82% Latinx, 12.62% African American, and 0.1% Native American. Nearly all of the participating students come from underrepresented groups in health-related science fields, and it is for this reason that we specifically target this population in order to help "level the playing field," so to speak, when it comes to sociocultural representation in STEAM-focused careers.

The program serves predominantly low-income students that are considered to be living in an "inner-city" environment. On average, 87% of students attending YSP-affiliated schools are eligible for free or reduced-price lunches. English Language Learners (ELL) Approximately 36% of students at the participating schools are identified as English Language Learners (ELL), and on average 98% of the participating ELL students speak Spanish. To facilitate culturally-sensitive pedagogy, all curricular materials are translated into Spanish.

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The authors would like to acknowledge the following individuals and organizations, without whom this contact would not have been possible: the Amateur Radio on the International Space Station (ARISS) organization, for supporting the event and coordinating with NASA to ensure that scheduling for the contact was possible; the Ham Radio Mentors and Technical Experts (Bob Koepke (AA6TB), Ron Grassl (AG6ST), Norm Thorn (K6UU), Darrell Warren (KA6OSC) and Brian Johnson (AB6UI)), whose collective radio expertise and equipment made this event possible; Liam Kennedy and the ISS ABOVE curriculum/ software and hardware, which played an integral role in preparing students for the contact event; all of the teachers, administrators, staff and students at Vermont Elementary School especially Principal Ms. Patricia Ferguson and Coordinator Ms. Maribeth Baccaro, who were beyond patient and accommodating with the planning and rescheduling necessary for this contact to happen; the media and public support from the Annenberg School of Communications and the Office of Mayor Eric Garcetti, who helped expand the breadth of circulation about this historic event; and of course, all of our YSP Teaching and Leadership staff, as well as the full-time staff at the Joint Educational Project who provided assistance throughout the journey. YSP and Vermont Elementary School would also like to thank Congresswoman Karen Bass and Jacqueline Hamilton, a representative from the Congresswoman's office, for marking this historic event by issuing certificates to the students, YSP Staff, ARISS volunteers and Vermont Staff (principal, teachers, and cafeteria workers).

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Earth Science All Around: Using Immersive Virtual Field Trips with Place-Based Instruction in Earth and Space Science Education

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Abstract

In this article we share ideas that were explored with teachers during a Geophysical Information for Teachers (GIFT) workshop at the annual meeting of the American Geophysical Union (AGU) in 2018. In that workshop we related the use of Immersive Virtual Field Trips (IVFTs) in geoscience education to principles of *place-based education* (PBE), which has an established research base within geoscience education (Semken, Ward, Moosavi, & Chinn, 2017). We argue here that IVFTs have several applications in geoscience education—including IVFTs that are created by individual teachers, K-12 students, or third parties and made available online.

Introduction

A bus comes to a stop at the edge of a rocky outcrop and a group of high school students move excitedly through the bus door, assembling in study groups that they've been assigned while they were still in their classroom. After a few reminders from the teacher, they spread out to different parts of the site, making observations, and collecting data that they'll share across groups when they return to school. While they're moving with focused purpose, there is also time to look around and feel the sensations that come from being in a natural setting. It is a day the students are likely to remember whenever they think of this place, or places like it.

Such experiences as the one described above have great potential in Earth and space science education. Questions emerge, however, as to how to make use of this experience in relation to classroom instruction, and how to focus instruction on specific places when it is not possible to take the whole class out in the field. As we describe in what follows, we believe that a set of resources known as immersive virtual field trips (IVFTs) have the potential to extend and enhance field-based experiences in geoscience education.

For many geoscientists and geoscience educators, what drew them to their discipline was an affinity for the natural environment. In many cases, these feelings have been strengthened through experiences in the environment—as learners, as researchers, and as individuals engaged in hiking, climbing, photography, and many other informal activities that include encounters with the wonders of the Earth. For this and other reasons, there is a general realization of the many-faceted values of making field work a fundamental part of geoscience education. Yet, opportunities for field work can be limited due to accessibility of sites, opportunities for travel within the academic calendar, cost, and other reasons. These challenges are especially problematic in today's K-12 Earth science classrooms where there is an increasing emphasis on connecting what is being learned to the students' lives—as individuals and as members of communities—which can be enhanced by real-world field experience. This combination of limitations and priorities suggests that it is important to find ways to extend field experiences in various ways, including through the use of technology. Among those technologies are what have become known as immersive virtual field trips (IVFTs). In this use, an IVFT is defined as a media resource that allows students to virtually explore the features of a real-world field site in ways that both mimic and enhance features that would be available if the student were having a firsthand experience at the site. While not replacing field experiences, IVFTs can be used to encourage students to think about geoscience, especially as it pertains to specific locations.

In essence, the applications of IVFTs in geoscience education focus on the use of IVFTs as tools to present phenomena in contextualized ways and allow learners to gather information—both through the IVFT and using additional online tools—and draw reasoned conclusions from evidence about those phenomena. The content focus of the exploration can be widely varied, including watersheds, fossils, rock formations, weather patterns, and others.

Immersive Virtual Field Trips

It must be recognized that there are many uses of the term "virtual field trip" as used in K-12 education. The attributes of the resources to which that label is applied vary widely in their structure and intent. While some of these share attributes with the types of IVFTs that we are addressing here, others are quite different. In some instances, for example, virtual field trips have been conceptualized as a structured set of online resources that provide students information about various topics. For example, see boeingfutureu.com/virtual-field-trip. In some of those cases the idea of a "field trip" becomes a metaphor for visiting websites online (and, therefore, using resources that are outside of the classroom). In some cases, the progression of ideas offered by the virtual field trip is set in advance, while in others the learners have options to visit different resources in different sequences. This type of virtual field trip tends to be focused on providing opportunities for learners to encounter and/or gather information related to the topics being addressed. There is less of an emphasis on the ideas as they are encountered within the context of a specific location, and the emphasis on learning about a site may or may not be part of the approach.

Other virtual field trips provide visual media related to a location, often with the goal of engaging students in the features of the location such that they are motivated to research those features as part of their learning. This approach is the foundation for the suggestions of technology applications at: commonsense.org/education/top-picks/virtual-field-trip-apps-and-websites; scholastic.com/teachers/articles/teaching-content/virtual-field-trips/. As well, there are virtual field trips in which the defining characteristic is that there is a live-streamed connection between the learners and the location, generally including some communication with scientists at the location. Consider the description given at: fieldtripzoom.com/wp-content/uploads/2018/03/teachers.pdf; discoveryeducation.com/community/virtual-field-trips/ These do often focus on specific locations, but in ways that tend to put less of the control of the exploration of the site in the hands of the students.

An important feature of IVFTs in our use involves the use of technology to allow learners a level of immersion, but also flexible control of the flow and movement through the visuals provided of the location, and of the virtual resources that are linked to those visuals. This interactivity provides learners with the potential to conduct virtual explorations of the site, which can lead to questions, investigations, and conclusions—essentially allowing the learners to engage with science and engineering practices (National Research Council, 2012) at the virtual location (**Table 1**).

Table 1. Science and Engineering Practices Central to IVFT's

Science and Engineering Practices
• Analyzing and interpreting data • Constructing explanations • Engaging in argument from evidence • Obtaining, evaluating, and communicating information

In some cases, IVFTs are structured to highlight specific features of a site and may even have specific guidance and embedded media to encourage attention to disciplinary ideas that are well illustrated within the context of the location. Within this structure, however, the learners retain a high degree of control. There are a wide range of ways of accomplishing this control. (For example, see a review of approaches within Gutierrez & Bursztyn, 2019).

Importantly, IVFTs may or may not be within the realm of virtual reality (VR) or augmented reality (AR). While some IVFTs provide VR and/or AR options (notably Google Expeditions, for example), this is not necessarily a defining attribute of IVFTs in the way that interactivity, learner control, and open-endedness are. That said, VR and AR have the potential to be highly immersive and there is evidence that it encourages learning about geoscience, especially when learners are allowed to explore the virtual environments open-endedly (Markowitz, Laha, Perone, Pea, & Bailenson, 2018).

Accessing Existing Immersive Virtual Field Trips

There are an increasing number of IVFTs for teachers to use that are accessible online. These are often developed for specific purposes, many of which are consistent with instructional goals addressed in geoscience classrooms. For example, the Center for Education Through eXploration (ETX) at Arizona State University (etx.asu.edu/) has released a series of open-access multimedia-rich IVFTs (vft.asu.edu/) (**Figure 1**) set in a number of pedagogically rich areas (e.g., Grand Canyon, Western Australia, K-Pg boundary sites around the world). The ETX IVFTs enable users to freely explore and study the surrounding landscape and its natural and human systems and, in some cases, directly experience scientific field research being carried out there. A recent paper by Mead et al. (2019) presents evidence for the effectiveness of these IVFTs in high-school and undergraduate learning settings.

Figure 1. Open-access multimedia-rich IVFTs created by the Center for Education Through eXploration (ETX) at Arizona State University.

Some IVFTs are designed to entice users to visit the focus site, such as those created around several national parks found on Google's Arts & Culture site artsandculture.withgoogle.com/en-us/ and others. An IVFT developed through a collaboration between the National Park Service Air Resources Division and the American Geosciences Institute (AGI) is meant to encourage visits to Shenandoah National Park, but also goes beyond that (nps.gov/shen/learn/photosmultimedia/air-quality-interactive.htm). This IVFT highlights the air quality research that is done at several locations in the park while allowing a high degree of user control over the field of view and sequencing within the experience so users can also engage openly with some of the park's key features.

Google also provides open-ended IVFTs through their Street View gallery google.com/streetview/gallery/. By providing minimal accompanying information, these IVFTs can be used in a variety of ways at several points in instruction, such as generating questions, making observations, and comparing the attributes of different settings.

Classroom-made Immersive Virtual Field Trips

Though there are many existing IVFTs for teachers to adapt and use in instruction, teachers also have many resources available to them to create their own IVFTs. The creation of custom IVFTs has the benefit of ensuring that the teacher is familiar with the location that will be brought into the classroom and understands how to highlight its relevance and encourage exploration of its meaning to students.

Teachers and students can both create IVFTs as part of instruction. An example of a teacher-made virtual field trip was created by Ryan Hollister, an award winning science teacher in Turlock, California, who was a member of *Science Friday's Educator Collaborative* in 2016 sciencefriday.com/segments/exploring-geologic-history-with-a-virtual-field-trip/. Mr. Hollister used what he refers to as *photospheres,* or 360° imagery, as the basis of his project. The construction of the IVFT was conscientiously done to maximize its curriculum potential. During the radio interview about the project, he described the experience of his IVFT in this way:

> *The first thing, you actually drop into is what I call a blank photosphere. So, there's six stops within this field trip. And basically, you can jump into the first photosphere with kind of no prodding and just cruise around and zoom in and zoom out and find things that look interesting.*
>
> *For students, we're going to be having them make field sketches, so you get a little bit more observational details that they may have otherwise missed. And you can kind of cruise around that. And then after you pop out of the blank photosphere, there's a bunch of information that'll tell you how to tell apart different types of rocks like granite and basalt.*
>
> — (Flatow, 2016)

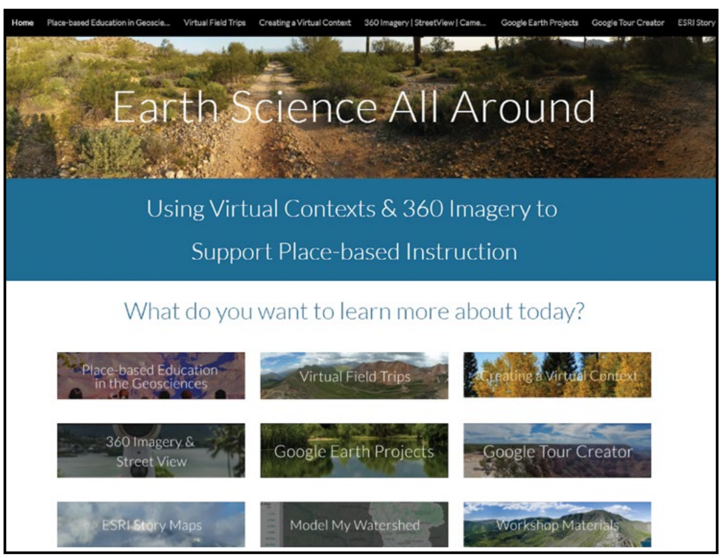

Figure 2. The *Earth Science All Around* website. The Workshop Materials section hosts the slides and handouts from the 2018 GIFT Workshop presentation.

The student-centered open-ended control that is encouraged in many IVFTs is articulated well by Mr. Hollister.

Yet another level of the curriculum potential of IVFTs can be realized when learners have opportunities to generate their own IVFTs. Student-generated IVFTs can be structured in ways that draw on the meanings that students associate with the places under study. The science-related ideas that are being addressed can be expressed in ways that are respectful of the students' place-based meanings. The website (**Figure 2**) containing GIFT Workshop materials on which this article is based, *Earth Science All Around*, sites.google.com/tothecloudedu.com/earthscienceallaround/home has practical resources and information for teachers who want to get started using IVFTs in their instruction.

Tools that can be used to create IVFTs include:

- **Google Earth Projects** - Tour creators developing tours in Google Earth Projects use scenes that are location-based and that include 360° StreetView imagery, video, images, text, lines/polygons, and techniques to engage viewers.
- **ArcGIS StoryMaps** – StoryMaps connect maps with text, images, and other multimedia content.

A geoscience-related topic or issue, such as using biogas as a low-carbon-footprint alternative fuel, the impact of human activity on watersheds, or specific content (e.g., the formation of columnar lava, fossil formations) can be connected to specific locations using IVFTs. Teachers can use existing IVFT resources, or they can learn how to use the images to engage learners in locally relevant topics.

Figure 3. Teachers explore various locations using Google Cardboard at the 2016 GIFT Workshop, *Images of a Changing Planet: Using Remote Sensing Data and Images to Investigate Land Surface Changes.*

Photo Credit: Aida Awad

Place-Based Education and Immersive Virtual Field Trips

While existing IVFTs provide a rich set of resources for teachers to use, it is likely that they will require some level of adaptation within a specific curricular use in a given instructional setting. Those adaptations many be related to such things as the specific subject matter highlighted by the IVFT, or the conceptual level of the embedded information as it relates to the learners. As well, while the locations that are the foci of IVFTs may be inherently fascinating to learners, there may be work to do to associate those locations with the learner's context in ways that build a sense of relevance (**Figure 3**). One promising approach is to apply principles of place-based education (PBE).

PBE is a type of situated teaching and learning that focuses content, instruction, and learning outcomes on *places:* any and all localities where people make and find meaning and form personal attachments (Tuan, 1977). This human imprint, which typically incorporates a spectrum of meanings affixed by many different people through time (cultural, historic, aesthetic, economic, as well as scientific) is what distinguishes a place from a simple location. The human connection to place is encapsulated in the construct of *sense of place,* defined as the combination of all meanings and attachments a person or a group holds for a given place (Brandenburg & Carroll, 1995).

The expectation underlying PBE is that learning science and practicing scientific skills in places that are familiar or interesting (and hence directly relevant) to students will better motivate them to learn, while also deepening their knowledge of their surroundings and encouraging them to share in local environmental and cultural protection and stewardship (Gruenewald & Smith, 2008; Sobel, 2004). Enriched sense of place—deeper meanings and stronger attachments—is an authentic student learning outcome of PBE that can be assessed quantitatively (Semken & Butler Freeman, 2008) or qualitatively (Ward et al., 2014; Williams & Semken, 2011), complementing more conventional assessments of knowledge, skills, and dispositions. Several recently published reviews and case studies (Apple et al., 2014, and other papers in the same issue; Semken et al., 2017) illustrate a wide range of application of PBE to Earth-science teaching at all grade levels and demonstrate its effectiveness.

PBE was long associated primarily with field- and community-based outdoor learning, so rendering virtual and online learning environments "place-based" may seem like an oxymoron. However, as technology and instructional design render IVFTs increasingly more immersive, the core characteristics or "design elements" of PBE (Semken et al., 2017) can now be implemented in the virtual realm:

- Focus lesson or course content on the natural attributes of the place under study;
- Meaningfully and appropriately integrate cultural attributes of the place under study, to add context and relevance;
- Teach with authentic experiences in the place or in an environment that evokes the place;

- Promote environmentally and culturally sustainable practices and policies in and relevant to the place; and
- Encourage and guide students to form their own intellectual and emotional connections to the place under study (i.e. enriching their senses of place).

Using IVFTs to Contextualize Content

As suggested by the IVFT created at Shenandoah National Park (described above), an IVFT can lead students to consider available scientific information and ideas in context—such as the air quality data gathered in the park. Through the IVFT they can relate that information and data to specific places, which may lead those places to have additional meaning to them. One way to think about the role of the locations and places that are the foci of IVFTs is that those sites are in effect providing examples of science concepts in context. Realizing this extends the use of IVFTs further as they can become opportunities to apply learning from more general tools in a specific location.

For example, the online tools in the *WikiWatersheds* website wikiwatershed.org/ allow exploration of many geoscience-relevant topics. Using the online *WikiWatershed's* "Runoff Simulator" and "Model My Watershed" apps, users are able to consider the effects of different ground cover scenarios on their watershed (**Figure 4**). IVFTs can help students virtually explore the ground cover in the watersheds of the images, even if they cannot take an in-person field trip. The intent is, of course, for students to develop increased awareness of the ways that human activity affects the hydrosphere, and other Earth systems.

Figure 4. Earth science educators are exploring the use of combinations of online tools, such as IVFTs and data collection applications available through *WikiWatersheds*, to support student investigations of their local context, which helps them build their sense of place awareness.

Photo Credit: Steve Kerlin, Stroud Water Research Center

Conclusion

> In a middle school classroom, students gather in groups around laptops and access spherical images that are connected to information, data, and other images related to a nearby canyon. The students have seen the canyon before as they have driven by it, but this interactive virtual field trips allows them to explore the site's features, and the science behind it. They have never had much experience with the site in person, but from now on, whenever they think about the site, or drive by it, they'll consider the ideas they've encountered in the virtual field trip.

While field experience will continue to play a central role in geoscience education—whether those experiences are part of a course or are undertaken for personal reasons, thereby contributing to a student's store of background knowledge, place meanings, and place attachments—IVFTs are resources that can help to expand the usefulness of experiences students have with respect to instruction. As well, emerging research indicates that the relationship can also happen in reverse. That is that the use of IVFTs prior to field work can help prepare novice students for a better learning experience when they actually go into the field (Ruberto, 2018). Much remains to be learned about the potential and influence of IVFTs in K-12 classrooms, but we believe that there are strong indications of their usefulness as resources to encourage Earth and space science learning in a place-based education framework.

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GLOBE Weather: A New Curriculum Unit for Middle School Uniting the GLOBE Program with Classroom Instruction to Meet Next Generation Science Standards

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Abstract

In this article, we are pleased to share an overview of the *GLOBE Weather* curriculum, including information about (1) the storyline of the unit, (2) how students gain experience with science practices through the curriculum, and (3) how we built in opportunities to address student misconceptions about weather. Teachers worked through parts of the curriculum during a Geophysical Information for Teachers (GIFT) workshop at the annual meeting of the American Geophysical Union (AGU) in 2018. *GLOBE Weather* is freely available online at globeweathercurriculum.org.

Introduction

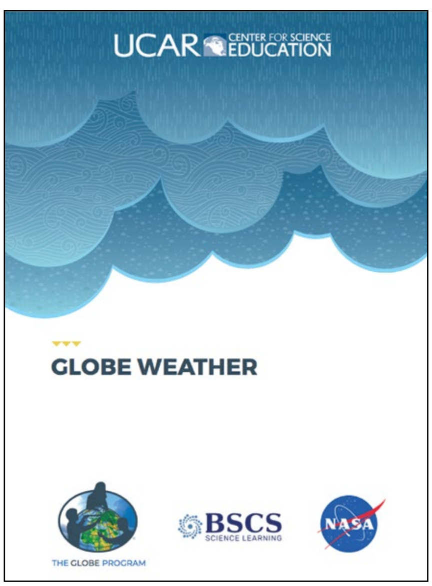

Figure 1. Cover of the *GLOBE Weather* curriculum. Download *GLOBE Weather* at globeweathercurriculum.org.

Students around the world have been collecting environmental data as a part of the GLOBE Program for over twenty years, exploring their local environments — the atmosphere, hydrology, soils, and biosphere — while also connecting with other students from around the world. We at the UCAR Center for Science Education sought to connect our expertise in weather and climate education with GLOBE in order to create a rigorous learning experience for middle school that meets Next Generation Science Standards (NGSS).

The result: *GLOBE Weather* (**Figure 1**), a five-week curriculum unit for middle school developed to directly address the NGSS, focusing on three Performance Expectations (**Table 1**). We developed *GLOBE Weather* over the past two years, in collaboration with the GLOBE Implementation Office and BSCS, with help from 24 field test teachers from across the U.S., and with funding from NASA. *GLOBE Weather* is aligned with three NGSS Performance Expectations. Note that strike-through text denotes concepts that are beyond the scope of the unit.

Focusing on student explorations of weather phenomena, with a storyline approach and modified 5E learning cycles, *GLOBE Weather* focuses on student analysis and interpretation of weather data, including data collected by GLOBE schools. Students develop graphic models to explain and document their understandings about weather and they make their own observations of the atmosphere following GLOBE Protocols. We've also included avenues for further explorations of weather through student research projects and connections with the GLOBE Program.

Table 1. *GLOBE Weather* Alignment to NGSS Performance Expectations

MS-ESS2-5: Collect data to provide evidence for how the motions and complex interactions of air masses result in changes in weather conditions.
MS-ESS2-6: Develop and use a model to describe how unequal heating and rotation of the Earth cause patterns of atmospheric ~~and oceanic~~ circulation ~~that determine regional climates~~.
MS-ESS2-4: Develop a model to describe the cycling of water through Earth's systems driven by energy from the Sun ~~and the force of gravity~~.

The GLOBE Weather Storyline

GLOBE Weather uses a storyline instructional approach to help sequence learning, allowing the story of weather to unfold gradually over five weeks. Over the course of the unit, student understanding builds as they figure out science ideas and put them together.

Each lesson focuses on questions, rather than topics, in order to keep the focus on exploration and discovery and help students manage the trajectory of their knowledge building. Students add their own questions into the story, keeping track of what they wonder using a Driving Question Board (**Figure 2**) and revisiting the board periodically to see if what they learn has helped answer any of their questions. The questions are both a record of students' curiosities and a way of documenting the progress that they make in understanding weather.

The storyline approach allows *GLOBE Weather* to be a journey to understanding weather. Each lesson within the unit focuses on a different phenomenon. It might be a surprising or puzzling phenomenon, something that students have come to accept but cannot explain, like clouds changing shape and size. It might be a phenomenon that students want to be able to predict and prepare for, like a violent storm. Or, it might be an everyday phenomenon that mystifies students when they stop to think about it, like why a small cloud spontaneously appears in a once completely clear sky.

With five weeks of instruction (approximately 25 50-minute class periods), *GLOBE Weather* begins with an Anchor lesson and continues with three guided-inquiry Learning Sequences that explore weather phenomena at increasing spatial (local, regional, and global) and temporal (from short-lived to ongoing) scales. Students first investigate weather at a local scale, then they learn about regional weather events such as storms that occur along cold fronts and the air masses that cause the fronts. In the final Learning Sequence, students investigate how global processes such as atmospheric circulation impact weather and how it moves around the world. The Culminating Task provides an opportunity for students to apply what they have learned with a new, related phenomenon. In addition to assessments at the end of each learning sequence and at the end of the unit, formative assessment opportunities are embedded within lessons.

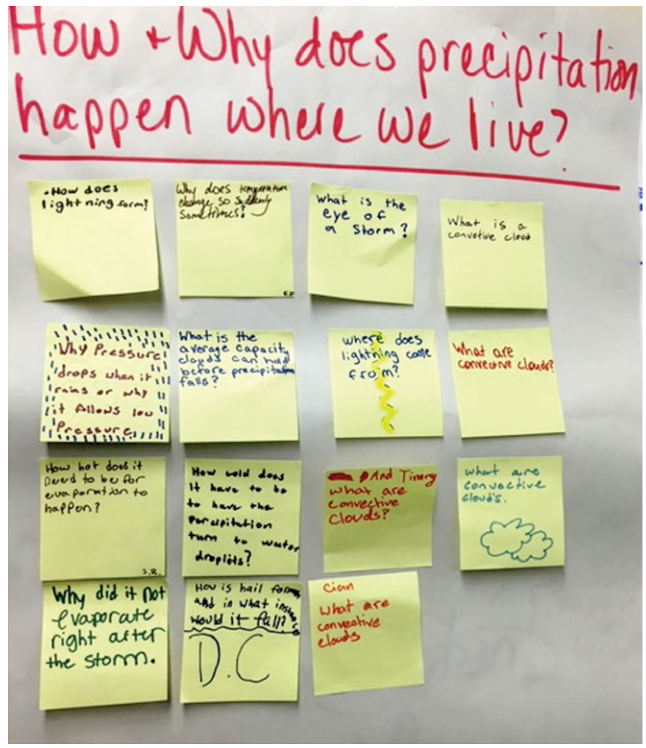

Figure 2. Example of a Driving Question Board.

Photo Credit: Denise Magrini, GLOBE Weather field test teacher.

Anchor: An Unexpected Storm. *GLOBE Weather*'s anchoring phenomenon, which students explore during the first lesson and then revisit periodically during the unit, is a precipitation event in which an unusually large amount of precipitation happened in a relatively short amount of time. Specifically, students learn about a storm that happened in Colorado in September 2013 which caused widespread flash flooding in Boulder County and the surrounding area. Students broaden from the specific storm to consider precipitation events that they have experienced. They begin to ask why and how moisture comes to be in the atmosphere and what causes it to fall as rain or snow.

Figure 3. Students warm air in a Mylar balloon to explore how warm air rises.
Photo Credit: Susan Oltman, GLOBE Weather field test teacher.

Learning Sequence 1: From Cloud to Storm. Students learn about weather at a local scale, investigating how cumulus clouds form over a day and how those clouds can develop into short-lived, isolated storms. Looking at the weather over a small geographic area allows students to also get to know physical aspects of the atmosphere, such as why temperature decreases with altitude within the troposphere and how energy from the Sun heats the land surface, which then warms the lower atmosphere. These topics are frequently misunderstood by students, so we built in opportunities for students to grow their understanding over several days (**Figure 3**).

Learning Sequence 2: A Front Headed Your Way. Students observe a time-lapse video taken during a day when a cold front moved through an area, causing a storm. They come to the conclusion that not all rainstorms are like the isolated storms that they investigated in Learning Sequence 1. They progress to investigations of how air masses collide at fronts, which can cause stormy weather over a larger region and over many days, especially at cold fronts where a cold air mass pushes into a warm air mass. Students learn how storms that happen along fronts impact larger regions than isolated storms. They analyze data to track the progress of a cold front over several days as it moves across the Midwest and eastern U.S. and then learn how air pressure helps air masses move, which then moves storms.

Learning Sequence 3: Worldwide Weather. Students zoom out to look at weather on a global scale, exploring how and why storms move around the world. Observing, analyzing, and interpreting information from weather satellites, air temperature data from GLOBE schools at various latitudes, and hands-on models of global atmospheric processes, students learn how the Earth is unequally heated by the Sun, causing global atmospheric circulation, which is affected by the Coriolis effect.

Culminating Task: Snow Day? At the end of the unit, students apply what they have learned about weather to explain a winter storm along a cold front that crossed the United States in February 2017. In the first challenge of the Culminating Task, students explain why it would rain in some California locations and snow in others. In the second challenge, students explain the pattern of snowfall in the interior West. In the third challenge, students predict where snow is likely to fall the next day in the Midwest.

Embedded NGSS Science and Engineering Practices

In *GLOBE Weather*, science and engineering practices provide the means by which students advance through the storyline. While students gain experience with many different practices during the course of the unit, we have built-in a particular focus on data analysis, constructing models, and planning and carrying out investigations.

Analyzing Weather Data. Students analyze weather data as a way of exploring storm phenomena in *GLOBE Weather*, including analyzing graphed and mapped data of temperature, precipitation, humidity, and wind. The weather data in this curriculum was collected by GLOBE schools, Community Collaborative Rain, Hail, and Snow (CoCoRaHS) citizen scientists, and the National Oceanic and Atmospheric Administration (NOAA).

Making Models of Weather Processes. Scientific models are sensemaking tools that help us to predict and explain the world. Developing models is the central activity in *GLOBE Weather*. Students construct models to organize their ideas and share their explanations of weather phenomena with others. While models can take many forms, the models in *GLOBE Weather* are graphics developed by students to document their learning about weather and how it works, including processes of the atmosphere and the water cycle (**Figure 4**).

Models support student sensemaking and help students visually articulate their ideas about atmospheric processes. The models that students develop throughout the unit can be used to track learning progress over time. The models are helpful tools for explaining what's happening in the system; however, like all models, they are imperfect. The atmosphere is more complex and chaotic than students will represent in their models, yet student produced models will represent the primary factors that affect weather, such as changes in temperature and moisture.

Planning and Carrying Out Investigations. In the unit itself there are implicit opportunities for students to use GLOBE Protocols (i.e., air temperature, surface temperature, clouds, and precipitation) to collect environmental data from their local environment. This is the first step in planning and carrying out an investigation. There are also extensions to encourage students to conduct their own research projects using GLOBE Protocols to investigate weather in their local area.

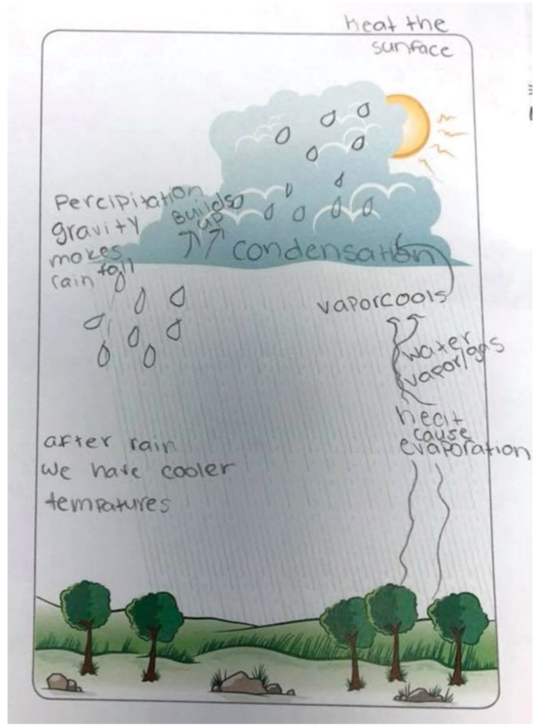

Figure 4. Example of a student model from Learning Sequence 1.
Photo Credit: Susan Oltman, GLOBE Weather field test teacher.

Addressing Student Misconceptions About Weather

Weather is something that we all experience everyday, which means that students are likely to walk into science class with preconceptions about weather and how it happens. Prior experiences with weather can provide a helpful foundation for learning the science of how and why weather happens, a foundation that students don't have for many other topics in science class. However, students may also have misconceptions about the science of weather based on their experiences.

During the two field tests of the *GLOBE Weather* unit, we asked teachers to document student misconceptions about weather. We took these misconceptions into account as we revised the curriculum to build in opportunities for students to confront misconceptions if they have them as they investigate weather phenomena. Additionally, we included content in the *GLOBE Weather* teacher guide that provides educators with information about common misconceptions about weather as identified by field test teachers (**Table 2**), and also the correct explanations for each.

Table 2: Common misconceptions about weather outlined in the *GLOBE Weather* teacher guide, and the Learning Sequence within the unit where they are addressed.

	Student misconceptions:
LEARNING SEQUENCE 1	Air is warmed directly by the Sun.
	Air that is higher in the sky is warmer because it is closer to the Sun.
	Peak air temperature happens when the Sun is highest in the sky.
	Clouds are made of water vapor.
	Confusion about how air temperature and humidity relate to isolated storms.
	It only rains when the humidity is 100%.
LEARNING SEQUENCE 2	Cold fronts happen in the winter because it's cold. Warm fronts happen in the summer because it's warm.
	A warm air mass is as warm as a tropical vacation. A cold air mass is freezing.
	Precipitation happens inside an air mass.
	Warm air holds more humidity because there is more space between molecules.
LEARNING SEQUENCE 3	It is warmer at the equator because it is closer to the Sun.
	Summer occurs when the Earth is closest to the Sun and winter when the Earth is farthest from the Sun.
	Heat from the Earth's core is responsible for heat at the Earth's surface.

Conclusion

In addition to Learning Sequences and a Culminating Task, *GLOBE Weather* contains embedded pre-assessments, opportunities for formative assessments, summative assessments for each Learning Sequence, and a final assessment. *GLOBE Weather* has been rigorously tested, meets Next Generation Science Standards, and is freely available online. During this time of uncertainty due to COVID-19 and its impacts on teaching, we have created a list of ideas to help use *GLOBE Weather* during at-home learning. Even though this curriculum was not created to be taught online, it can be adapted for this situation and serve as an excellent resource for teachers and students. Visit scied.ucar.edu/globe-weather-curriculum/resources/at-home-learning to find out ways to modify *GLOBE Weather* lessons for online learning.

About the Authors

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Soil: More than the Dirt under your Feet!

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Abstract

People all over the world see soil, walk on soil, and grow things in soil every day, but the vast majority of people never recognize how important soil is in sustaining life on Earth. Most people likely view soil as "just dirt," something that they would usually avoid coming into contact with and normally don't think much about. In reality, soil is a highly complex, relatively thin layer of generally loose mineral and/or organic material at the Earth's surface which supports biological activity, acts as a medium for plant growth, and performs many other critical functions. Soil is essential to all life on Earth because it performs crucial functions such as water purification and nutrient cycling, providing a habitat for living organisms, and sustaining the growth of plants that are used to produce food, clothing, and energy. This article presents background information linked to teaching resources that can be used to introduce K-12 students to many of the critical functions of soils. These materials were shared with teachers during a Geophysical Information for Teachers (GIFT) workshop at the annual meeting of the American Geophysical Union (AGU) in 2018.

Soil is the foundation for all terrestrial ecosystems, and because it is always underfoot, it is almost always overlooked, and too often underappreciated.

Soil Formation

Five factors interact in the formation of a soil, abbreviated as **ClORPT**: **Cl**imate, **O**rganisms, **R**elief, **P**arent Material, and **T**ime. It only takes a little bit of loose material, a little bit of water, and a seed for a plant to grow.

All soils have depth; a vertical cross-section of a soil is called a profile. These profiles develop over hundreds or thousands of years as loose mineral materials are changed through additions of various mineral and organic compounds, transportation of minerals and organic matter through the soil profile, loss of soil particles or soluble elements and compounds from the profile (from the top or out the bottom), and transformation of minerals through chemical and biological processes. Eventually, soil particles build up in certain places to create deep soil profiles that can support plant growth, while mineral particles are lost from other areas, leading those places to have shallows soils or, in some cases, no soil at all. When plants grow and die, plant residue is incorporated into the soil. This plant residue is broken down by microbes and becomes soil organic matter.

Figure 1. Plants grow anywhere.
Photo Credit: Clay Robinson.

The kinds of plants growing in an area can make a big difference in the soil that forms (**Figure 1**). Grasses have fibrous root systems and contribute organic matter as those roots grow and die every year, resulting in very dark soils with high organic matter contents. Trees have much larger roots that do not decompose quickly, and their leaves are deposited on the soil surface where they decompose, resulting in lighter-colored soils with less organic matter. The combination of mineral particles, decomposed organic matter, and living organisms make up soil.

Soil Properties

Figure 2. A soil profile showing the distinct layers within it.
Photo Credit: Clay Robinson.

Students can engage in several hands-on activities to measure basic soil properties (**Figure 2**) and think more deeply about how those properties influence how soils can be used and how they can support life. Many examples of activities are available online such as on the Soil Science Society of America's (SSSA) Soils 4 Teachers website (soils4teachers.org). Here, we highlight a few activities that work well as stations for small groups of students and require only basic materials to complete, thus making them accessible for all students.

Soil Physical Properties

One of the most important physical attributes of soil is the soil texture, or the proportion of sand, silt and clay-sized particles. Sand grains are large and easily visible with the naked eye and feel gritty when rubbed between your fingers. Silt grains are small and not easily seen with the naked eye but feel smooth when rubbed between your fingers. Clay particles are the smallest soil particles that often feel sticky and are especially good at holding water and clumping soil together, much like the clay you use to mold a piece of pottery.

Figure 3. Jar with water used to separate soil into clay, silt, and sand to determine percentages.
Photo Credit: Clay Robinson.

Soil texture can be easily measured by separating the different particle sizes by density; when mixed with water, larger and heavier soil particles will settle to the bottom of a jar faster than lighter smaller and lighter soil particles. When soil mixed with water is allowed to settle overnight, layers of sand, silt, and clay can then be observed, measured and the proportion of each particle size calculated as follows:

1. Fill a jar 1/3 full with <2 mm ground soil. Break apart any large clumps.
2. Add water to jar until jar is 2/3 full.
3. Shake vigorously to break up all soil clumps.
4. Let jar sit overnight to settle.
5. Find the beginnings and ends of the layers in your bottle of soil that you shook yesterday (**Figure 3**).

6. Measure the thickness or height of each layer.
7. Now sum the clay, silt and sand layer thickness to determine the total thickness.
8. Divide the height of each layer by the total height and multiply by 100 to find percent. The sum of all three layers should equal 100%.

Alternatively, this video describes another method to determine soil texture using a hydrometer: youtu.be/u8Pb2g8T4-8

Soil Color

Soil color can tell us a lot about the soil and the environment in which the soil has formed. What are some typical colors of soil? Red, Brown, Yellow, Black? These colors are often not the color of the minerals in the soil but are coatings of iron oxides (Fe_20_3, FeOOH, etc) or organic matter on particles. The minerals beneath are often quartz or feldspar which are grey in color. Dark black topsoil (grasslands) indicates the presence of high organic matter content as compared to light brown topsoil (deciduous forests). The presence of gray colors in the soil is used to determine how high the water comes in the soil even when the soil is dry. Looking for gray colors related to the water table is often done when assessing the site for many land uses related both to agriculture as well as urban/suburban development. Often the gray colors are referred to as wetness mottles or redoximorphic features (formed from reduction and oxidation (redox) chemical reactions in the soil). Many land use decisions are based on these colors and the fact that they do not change season to season. Thus, in summer when water tables are deep in the soil, gray colors indicate how high the water table will rise during the wettest time of the year. The color change from red (rusty) to gray in the soil is due to reduction and oxidation of Fe. This process occurs in soil but in saturated soil this occurs when Fe^{3+} is reduced to Fe^{2+} due to a microbial mediated redox reaction.

Students can demonstrate how coatings affect soil color by using red M&Ms™ following the few simple steps below:

1. Place a few M&Ms™ in a sieve. They are still red.
2. Slowly immerse them in water and gently shake them. The water will start to turn pink as the red dye is washed off.
3. Observe the color change and remove them before the underlying white coating is dissolved.
4. Dry them. They are now white to pink.

A similar process occurs in soil. For example, in saturated soil this occurs when Fe^{3+} is reduced to Fe^{2+} due to a microbial related redox reaction.

If air (O_2) is in the soil the soil is aerobic

- $4e^- + O_2 + 4H^+ \rightarrow 2H_2O$

If all O_2 is removed, soil becomes anaerobic (saturation occurs)

- Denitrification
- $10e^- + 12H^+ + 2NO_3 \rightarrow N_2 + 6H_2O$ – no color change
- Iron (Manganese) Reduction
- $2e^- + 6H^+ + Fe_2O_3 \rightarrow 2Fe(II) + 3H_2O$ – soil turns gray
- Sulfate Reduction
- $8e^- + 10H^+ + SO_4 \rightarrow H_2S + 4H_2O$ – rotten egg odor

So why is this reaction important? It helps soil scientists identify where the water table is even when the soil is not saturated. Once the gray colors have formed from Fe^{3+} reduction and removal, it is unlikely that the particles will become coated again. Since this reaction occurs in saturated and reduced or anaerobic conditions, the presence of gray colors indicates where the water table is in that soil. This helps soil scientists identify wetland or hydric soils and locate suitable soils for septic systems and related land use. This reaction only occurs if there are enough microbes and a food source (carbon) present to cause anaerobic conditions to occur.

Soil Chemical Properties

Soil pH, or the acidity or alkalinity of the soil, and soil nutrients, such as nitrogen (N), phosphorus (P), and potassium (K), are important for nourishing plants and organisms in soils, and these properties are easily measured by students using a simple garden soil test kit. Most soils range in pH from about 3.5 to 10.5, with a more neutral pH around 7 considered optimal pH for most plants and soil organisms. Soil nutrients are naturally released through the breakdown of soil minerals and organic matter, although they are sometimes added as fertilizer to boost soil nutrition.

A soil test kit to measure nutrients and pH is inexpensive and can be purchased from a garden center and usually includes plastic test wells and capsules of reagents to react with water and nutrients in the soil. The nutrient or pH level is assessed by comparing the color of the water with a standard color chart. Some kits call for dry soil to be added directly to the plastic wells before adding water and the capsule, although extracting the soil water first can make detecting color changes more straightforward for students. To extract soil water, add water and soil in a jar, shaking to suspend the soil in water. Allow the soil to settle overnight, and then carefully pour out just the water sitting on top of the soil for use in the test kit. This activity pairs well with the soil particle size activity described above since students have already allowed soil to settle in water.

Soil Biological Properties

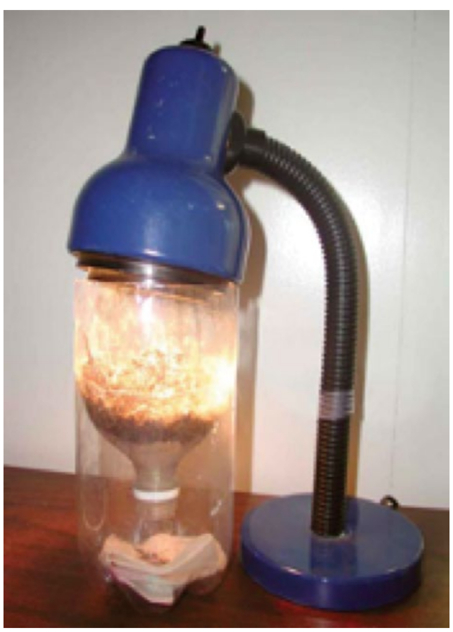

Figure 4. Berlese funnel made with a plastic soda bottle, rubbing alcohol, and a desk lamp.

Photo Credit: Natural Resources Conservation Services.

Soil is full of life and is one of the most diverse ecosystems on earth. In fact, a tablespoon of topsoil may contain well over one million organisms! Soil biota include plants, animals, and microorganisms that help break down soil minerals and decompose organic material to return nutrients to the soil. Plants play an important role in soils by growing roots that help break up compacted soil and allow water and air to enter soil when the roots decompose. Earthworms are one of the easiest soil organisms to identify, and also help air and water move into the soil through their burrowing activity. Microorganisms, such as bacteria, protozoa, algae, and fungi, are important for breaking down organic and mineral material, but are too small to see with the naked eye.

An excellent teacher resource about the soil food web and soil creatures can be found on the Natural Resources and Conservation Service nrcs.usda.gov website. Teachers can download The Soil Biology Primer for free or they can order a hard copy from nrcs.usda.gov/wps/portal/nrcs/main/soils/health/biology/.

Students can explore life in the soil by constructing Burlese funnels, which are funnels that help to extract organisms from a soil so they can be examined, ideally under a microscope. The funnel can be made from a plastic soda bottle cut in half with the top inverted into the bottom half of the bottle (**Figure 4**). Soil is placed in the newly created funnel, and rubbing alcohol is added to the bottom of the bottle to "trap" organisms. A desk lamp is placed over the top of the bottle, and because the organisms move away from the heat and dryness created by the lamp, they will move to the bottom of the funnel and get trapped in the rubbing alcohol after several days. The organisms can then be examined with a hand lens or microscope, and some nematodes, arthropods, and earthworms can be identified. Students can count, identify and compare organisms in different soils and consider how these organisms fit into the larger food web of soils.

Connecting Soil Science to Science Learning Standards

Soils are the great core idea connecting physical, life, and Earth and space sciences, and they lend themselves well to three-dimensional (3-D) teaching and learning as prescribed by the Next Generation Science Standards (NGSS). Soils can be investigated for their geologic origin, their organic matter and life, their chemistry, and the physics that explains how fluids migrate in soils. In 3-D teaching and learning, students employ science and engineering practices and crosscutting concepts to build understanding of disciplinary core ideas embedded in student-friendly phenomena such as a case study related to soil erosion or plant growth.

As states and districts are developing innovative ways to ensure all students engage in all science standards, soil science is a thread that unites many disciplinary core ideas. Using middle school science as an example, soil science is found in the following Earth and Space Science disciplinary core ideas: Earth Materials and Systems (ESS2.A), The Role of Water in Earth's Surface Processes (ESS2.C), Weather and Climate (ESS2.D), Natural Resources (ESS3.A), Natural Hazards (EES3.B), and Human Impacts of Earth Systems (ESS3.D). In the case of middle school life science disciplinary core ideas, soil science is naturally connected to: Interdependent Relationships in Ecosystems (LS2.A), Cycles of Matter and Energy Transfer in Ecosystems (LS2.B), and Ecosystem Dynamics, Functioning, and Resilience (LS2.C). In the case of middle school physical science disciplinary core ideas, soil science is naturally connected to: Structure and Properties of Matter (PS1.A), Chemical Reactions (PS1.B), and Energy in Chemical Processes and Everyday Life (PS3.D).

As an example of how to integrate the NGSS disciplinary core ideas with science and engineering practices, and crosscutting concepts, the K12 Committee of SSSA developed a middle school soil science unit that integrates these three dimensions centered on the following essential questions:

- How do soils sustain life and influence life as abiotic and biotic factors in an ecosystem? (Part 1)
- What are the five soil formation factors (ClORPT) and how do they contribute to the formation of soil? (Part 2)
- What are the characteristics that differentiate a soil from other soils (i.e. particle size/texture, structure, color, profile) and how do these characteristics contribute to soil quality and function? (Part 3)
- What are the challenges of ensuring soils are sustained into the future, and how can we address those challenges? (Parts 4)
- How do soils contribute to society: the products we use, places we live? (interdisciplinary) (Part 5)

The unit with links to the activities can be found at the Soil Science Society of America's (SSSA) Soils 4 Teachers website (soils4teachers.org) (**Figure 5**). The SSSA is a professional scientific society, made up of soil scientists, educators, and consultants focused on promoting soil science, including enhancing soils topics in schools. The Soils 4 Teachers website provides resources for teachers on multiple soil topics. There are lesson plans and activities for different grade levels and topics. Topics range from general soils lessons (composition, color, texture, formation) to soil chemistry (soil pH, nutrients, chemical reactions) to soil biology (soil organisms, decomposition, composting) to soil forensics and more. Resources include State Soil Booklets that detail what a state soil is, what makes the state soil unique and important for each state. Coming soon to the Soils 4 Teachers

Figure 5. K-12 Soil Science Teacher Resources from the Soil Science Society of America.
Photo Credit: Public domain screenshot.

website is a searchable database of vetted resources to support K12 teaching of soil science. Users will be able to search by topic, grade-band, NGSS disciplinary core idea, and type of resource.

In addition to the soil science resources found on the SSSA Soils 4 Teachers Website, the GLOBE Program also includes soil science protocols. The Global Learning and Observations to Benefit the Environment (GLOBE) Program's mission is "to promote the teaching and learning of science, enhance environmental literacy and stewardship, and promote scientific discovery". Educators and students can dive into the scientific process and collect data in their local environment and be a part of real, hands-on science that contributes to how we understand our global environment. Students and educators can connect with other students, educators, and scientists around the world through the GLOBE collaborations and regional offices.

Looking for grade level-appropriate, interdisciplinary activities developed by the scientific community and validated by teachers? GLOBE has you covered for investigating the soil/pedosphere through the GLOBE Teachers Guide at globe.gov/do-globe/globe-teachers-guide/soil-pedosphere. In the Data Game activity, students learn how data can be distorted and learn to think critically about data being presented. Other activities explore how soil moisture and temperature can vary across a landscape, how water moves through soils, and how organic materials are decomposed in soil.

To connect students to the soil in their backyard without going outside, the Web Soil Survey (websoilsurvey.sc.egov.usda.gov/App/HomePage.htm) from the Natural Resource Conservation Service provides teachers the opportunity to explore the soils of the US without having to leave the classroom. Students can explore the various soil types and soil classifications of specific areas that they select. Would the site they selected be a good place to grow a crop, build a house or road? Information includes what limitations may exist for supporting plant growth, such as shallow soil depth or frequent flooding and limitations for housing, such as septic tank absorption field suitability.

Conclusion

Soil is not dirt! These lessons and references should help students understand the complexity of soils. In a science curriculum soils can be used to teach about: physics – particle size, gravity and settling; chemistry – color, reduction/oxidation, pH, nutrients; biology – Burlese funnel and microbial mediated color changes; GIS and Technology – Web Soil Survey; and so much more. Resources abound (GLOBE, NRCS, Soils4Teachers, etc.) to help educators find lesson plans and materials that can be adapted to any classroom and any age. Furthermore, adoption of soils into lesson plans fits well within the NGSS in many ways. Best of all, soils represent the real world. They allow students to apply fundamental principles to something they can touch and that affects their lives in so many ways. Soils are fundamental to all life so if you know soils you know life and with no soils there is no life. So, go out and get dirty.

About the Authors

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Enhancing a Connection to Place: Recognizing Indigenous Culture in a Western Science Activity

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Abstract

The BioBlitz (BB) is a National Parks Service citizen science activity that involves the general public in assessing and documenting the biodiversity of a variety of habitats within a given area. In an effort to make the National Parks BB activity more accessible for Native American students, we have adapted it to encourage Native American youth to explore the environmental science issues and concepts in their community. The revised Back to the Earth BioBlitz (BTTE-BB) activity focuses on building awareness for the local environment and a connection to place. This activity compels students to use authentic science skills to document and assess the biodiversity in their local (community) watershed. The purpose of this article is to provide K-12 science, technology, engineering and math (STEM) educators a simple activity that places importance on attending to "other ways of knowing" while maintaining a focus on scientific content and the skills of science inquiry.

Introduction

Investigations of the environment—an ecosystem, and even one's backyard—include learning content and skills that can encompass the history of a place and even a reflection of the past. Developing instructional activities with an eye on cultural relevance can bridge the gap between Western and Indigenous knowledge to provide culturally inclusive science learning that can motivate racially diverse students' interest. The National Parks BioBlitz (BB) (National Parks Service, 2015) was adapted for use in a National Science Foundation (NSF) funded STEM summer camp for Native American youth.

The Back to the Earth (BTTE) program was a culturally-rich STEM education program developed by University educators in collaboration with a local Native American tribal community. The target audience for the BTTE program was youth, grade 3-6. The activities outlined in this article are appropriate for tribal youth ages 10-13. The program was developed to promote Native American students' access to science as well as encourage their interest in STEM careers in the local community. The revised activity, the Back to the Earth BioBlitz (BTTE-BB), instructs Native American youth to explore concepts and skills while acknowledging the unique epistemological understanding of Indigenous knowledge as "ways of being" which recognizes their personal perception of what constitutes a good life (Brayboy & Maughan, 2009, p. 4). The BTTE-BB activity aligns with the Next Generation Science Standards (NGSS) MS-LS2-1. Ecosystems: Interactions, Energy, and Dynamics (NGSS Lead States, 2013). This relationship is further defined under **Table 1**.

Table 1. Back to Earth BioBlitz Activities Alignment with the Next Generation Science Standards (NGSS Lead Standards, 2013)

Standard

MS-LS2-1. Ecosystems: Interactions, Energy, and Dynamics http://www.nextgenscience.org/pe/ms-ls2-1-ecosystems-interactions-energy-and-dynamics

Performance Expectation

MS-LS2-1. Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.

Element	Name or NGSS code/citation	Activity connection
Science and Engineering Practices	**Analyzing and Interpreting Data** • Analyzing data in 6–8 builds on K–5 experiences and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis. • Analyze and interpret data to provide evidence for phenomena.	• Students collect physical, chemical, and biological data from each habitat location and record their findings onto an electronic spreadsheet via iPad during activity 2 (Habitat Investigation). • Data is analyzed and interpreted as a group during activity 3 (Reconnection to Place) to determine if the local aquatic ecosystem would support future salmonid populations.
Disciplinary Core Ideas	**LS2-A: Interdependent Relationships in Ecosystems** • Organisms, and populations of organisms, are dependent on their environmental interactions both with other living things and with nonliving factors. • In any ecosystem, organisms and populations with similar requirements for food, water, oxygen, or other resources may compete with each other for limited resources, access to which consequently constrains their growth and reproduction. • Growth of organisms and population increases are limited by access to resources.	• During the habitat investigation and concluding analysis, students observe the symbiotic, dependent relationship between all things found within an ecosystem. • Students learn of their cultural co-dependence with the natural environment during the first activity (Community Engagement) from tribal members and Natural Resource personnel.
Crosscutting Concept	**Cause and Effect:** • Cause and effect relationships may be used to predict phenomena in natural or designed systems.	• During the third activity (Reconnection to Place), students reflect on their cultural connection to the symbiotic, dependent relationship observed in nature.

The revised BTTE-BB incorporates a holistic or systematic view of nature that aligns with an Indigenous philosophy where nature encompasses both "living" and "non-living" things. The typical National Parks BioiBlitz (BB) Activity is a qualitative and quantitative place-based experience (Semken. et al. 2017) that facilitates the assessment of all living things and excludes "non-living" entities (National Parks Service, 2015). The BTTE-BB activity focuses on a holistic investigation of all "things" that can be found within a selected environment and used to orient the youth to their place.

Often, a westernized scientific activity, such as BB, can be in conflict with the holistic view that many Native American people hold. Western science places a distinction among living (i.e., plants and animals) and non-living things (i.e., rocks and water) in the ecosystem, the non-living tend to be less defined, or indistinct. This conflicting view provided the impetus to refocus and adapt the BB lesson to include Indigenous knowledge and ideology, which embraces everything that is made by the "creator." Brayboy and Maughan (2009) further clarify this conflict in their statement:

> "Individuals concerned with knowledge in this traditional Western sense focus on the search for eternal truths, laws, and principles that may be proven through the posing of hypotheses, test construction, and "scientific" experimentation. Indigenous Knowledge, however, is contextual and contextualized; they are lived and are an integral part of survival." (p. 11-12)

One of the most prevalent Western concepts found in the BB is the distinction between biotic (i.e., living; fish, trees, insects) and abiotic (i.e., nonliving; soil, water, rocks) entities. This separation, however, does not align with a holistic viewpoint of Native American communities, which embraces a systematic relationship in the environment (Brayboy & Maughan, 2009). Unlike Western science, Indigenous knowledge does not categorize the environment into separate entities, there is no distinction between nature and culture, thus abiotic or non-living things such as a rock or a stream are considered to be "alive," and part of the biotic or living world (Berkes, 2012). Acknowledging Indigenous knowledge values and a Western science education in the BTTE-BB, students were asked to list the systematic relationship between ALL things within a given ecosystem.

In order to achieve a holistic investigation of the environment, the BTTE-BB was organized into three parts, I) Community Engagement and Pre-activity Discussion (introduction and background discussion), II) Habitat Investigation, and III) Reconnection to Place (extension-reflection opportunity). Each activity was held in a local outdoor setting that included a small stream (e.g., aquatic habitat), neighboring wetland (e.g. semi-aquatic habitat), and forested environment (e.g., terrestrial habitat).

While an overall ecosystem assessment, as identified in a traditional BB, was not completed in the BTTE-BB activity and affiliated lesson, the traditional BioBlitz activity developed by the National Parks service provide a full habitat assessment in collaboration with a local citizen science program (see: nps.gov/subjects/biodiversity/national-parks-bioblitz.htm). Other full habitat assessment programs, such as IDAH2O (University of Idaho Extension, 2019) is a citizen science program, affiliated with the University of Idaho, which trains the general public (e.g. citizens) to collect biological, chemical, and physical data within an aquatic ecosystem. Ultimately, after the data has been recorded, it can be shared with a local land management agency (i.e., Native American tribe) for record and assistance for their monitoring programs.

Figure 1. Natural Resources Department presentation on the significance of salmonid populations for the local environment and tribal community.

Community Engagement and Pre-activity Discussion

To begin the BTTE-BB activity, an introduction to the area (i.e., place) in relationship to the significance of salmonid populations for Native American tribal culture and the environment should be presented by personnel from the tribe's Natural Resourced Department or members of the tribal community (**Figure 1**). During this presentation, students are told that salmonids (i.e., salmon, trout) are a major cultural food for Native American people (see *Shadow of the Salmon* curriculum, 2015). In the western half of the United States, native salmonid populations have been drastically reduced in number due to an altered landscape (i.e., dams, reservoirs) caused by changing population dynamics (Donley, Naiman & Marineau, 2012). Today, several Native American tribes are actively engaged in revitalizing the population of this vital food source to benefit the environment and cultural sustainability of the tribal community (i.e., USFW, 2019). Therefore, the context of this presentation provides the groundwork for students to recognize an Indigenous epistemology, which acknowledges the interconnection between the physical and spiritual worlds.

Presentations of ecosystem relationships, such as salmonid populations in an aquatic ecosystem can be adapted to incorporate a variety of environmental issues impacting a Native American community's traditional way of life. For example, this lesson could reflect the impact of non-point source pollution on culturally-relevant food (i.e., deer, elk, camas, huckleberry, etc.) for Native American communities within the inland, Northwest, United States. The lesson and affiliated activities should be developed to reflect the environmental issues impacting the partnering Native American community. Thus, this information should be gathered from the affiliated community before developing the environmental focus of the presentations.

Approximate time for lesson: one-hour block of time.

Activity directions

1. The teacher (or leader) gathers students at the field study site for an explanation of the BTTE-BB activity. The teacher should provide a definition of key terms (i.e., biodiversity, organism, habitat).
2. Identify and define the three habitats (aquatic, semi-aquatic, and terrestrial) in the local ecosystem (e.g., the study site, **Figure 2**.)
3. Students should consider how each habitat is connected in the entire ecosystem, salmonid health, and furthermore their own livelihood in order to recognize Native American holistic epistemology within this STEM activity.

Habitat Investigation

The ecosystem of a local stream (**Figure 2**) is assessed through the investigation of three adjoining habitats; aquatic, semi-aquatic, and terrestrial. Aquatic habitats are generally understood as those natural environments containing water (i.e., streams, ponds, oceans). Semi-aquatic habitats occur where the water meets the land and are often found between an aquatic and terrestrial habitat (i.e., wetland, marsh). Terrestrial habitats are non-aquatic environments that support forests, prairies, and deserts. In each habitat, students collect "data" with the use of bug jars, magnifying glasses, field books, and personal senses. The students are told to thoroughly explore each habitat and keep a tally (on a data sheet or iPad) of all the things (i.e., bugs, birds, animals, fish, plants, soils, etc.) that were found in each area. At the end of each habitat assessment, students are asked to note if the habitat could support future salmonid habitats (i.e., cool, clean, well oxygenated water; riparian vegetation; variety of substrate (rocks, logs)). Through this holistic exploration of a local habitat, students become more oriented to their place and are able to consider the systematic relationship between each habitat and their own culture within the environment.

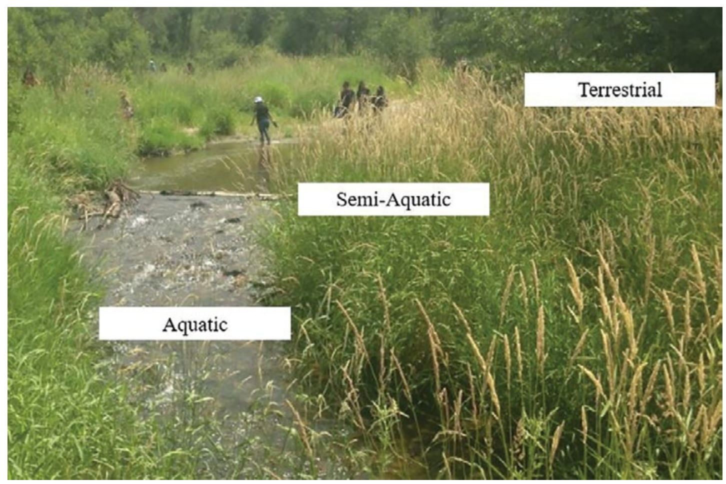

Figure 2. Terrestrial, semi-aquatic, and aquatic habitats located in the given study site.

Approximate time: two-hour block of time.

Activity directions

1. Students should be divided into small groups (about 4-5 students) and preferably with one adult volunteer for each group. Each group is assigned a given habitat (aquatic, semi-aquatic, terrestrial) within the ecosystem. After 30 minutes each group will be instructed by the teacher to change habitats, until all groups have assessed all three habitats.
2. As a group, the lead instructor should indicate the three habitat areas in which the assessment will take place. The 'size' of the habitat to be assessed for all things is subjective to the chosen outdoor environment.
3. After the teams have been divided and the habitat assessment areas have been identified, students should collect all necessary field equipment. Equipment can include a variety of items such as magnifying glasses and jars to observe all things located in the given habitat as well as plant, animal, and insect identification books. iPads/notepads

and a 'tick-sheet' can also be used to record an inventory of all things (i.e., living and non-living) within each habitat.

4. Once the equipment is collected, students should conduct an assessment for each habitat. To perform the assessment, each student should observe the given habitat and note the number and if possible, the available species within the biological community (i.e., vegetation, insects, animals) in addition to the physical characteristics (i.e., soil composition, geology, topography), and chemical conditions (i.e., water, air, and soil temperature) (**Figure 3**). Once identified, students should record their findings on the tick sheet and take photos via iPad for documentation (**Figure 4**). This activity is purely observational, nothing is to be removed from the natural environment.

Figure 3. Tribal youth collecting biological data in the aquatic habitat.

Figure 4. Tribal youth recording data in the terrestrial habitat.

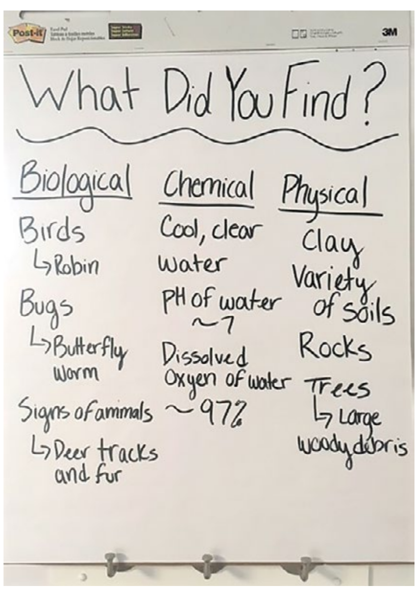

Figure 5. Findings from the habitat investigation (Activity 2) displayed on a large sheet of paper.

5. After each group has completed their inventory and assessment, all three groups should gather to share what they have found, the characteristics of their habitats, and the interconnections observed within the given ecosystem.
6. While each student group shares their findings, the teacher should compile all the findings on a large sheet of paper (**Figure 5**).
7. Once the student group data has been compiled, the students should be asked by the teacher to provide an overall assessment of the ecosystem and the "viability" of salmonid restoration in the area.

Reconnection to Place

As an extension to this lesson, to reinforce the importance of "place" for Native American youth, the students should engage in a "what makes your heart sing" reflective activity. This activity has students share something they encountered in the local environment they studied that warmed their heart and made them think of "happy, thankful, joyful" thoughts, memories, and/or feelings. Native American elders want their youth to understand and know how vital self-determination is to today's Native American way of life. Thus, the "what makes your heart sing" activity is meant to further the students understanding of place and their connection to their land. Connecting students to the local ecosystem demonstrates the intimacy of their role and kinship to the place and the environment. This understanding facilitates a sense of responsibility, stewardship, and guardianship for their community's place and environment. A realization of sovereignty (i.e., self-determination) and management for the environment inspires the interest and hopeful ownership of one's land.

Approximate time for lesson: one-hour block of time.

Activity directions

1. To re-affirm the student's connection to their place, students share "what makes your heart sing" about the local environment in small groups and then as a class.
2. The teacher should write down answers on a large piece of poster paper.
3. Answers are then shared with the group to enhance their sense of stewardship and guardianship for their place.

Conclusion

The BTTE-BB was adapted to accommodate a Native American epistemology that provides a holistic and culturally reflective investigation of a local ecosystem. This activity aims to deepen student's connection to place and interest in the STEM career field by engaging them in exploring STEM within their local community. While the typical BB is an activity for assessing the local biodiversity within an ecosystem, it is heavily based in Western science, where a Western science epistemology is emphasized (i.e., nature encompasses only living things). Incorporating "other ways of knowing" within a STEM curriculum will enhance an Indigenous cultural connection to STEM and encourage youth to discover their place within this field.

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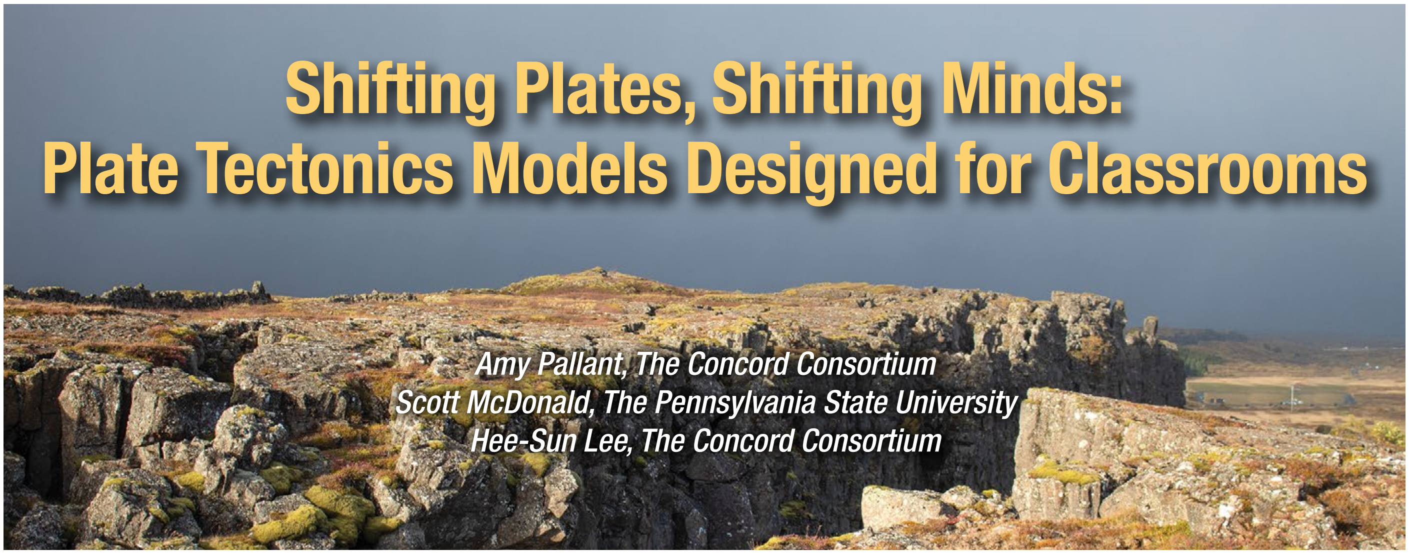

Shifting Plates, Shifting Minds: Plate Tectonics Models Designed for Classrooms

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Abstract

Understanding Earth's tectonic plate system dynamics is complicated though it is the central paradigm to explain transformations of Earth's surface. The landforms and geodynamic events resulting from plates interacting are too massive to observe at scales of human experience. It is difficult for students to connect plate movements to geologic features like the Andes Mountains and geodynamic events like earthquakes. As such, the conventional teaching of plate tectonics rarely involves student-led systematic explorations. This article introduces a new online curriculum module called "What will Earth look like in 500 million years?" Using two web-based tools, middle and high school students develop understandings of (1) how collective movements associated with a system of plates create the current distribution of landforms found on Earth's surface, and (2) how earthquakes and volcanoes provide important clues for interactions at plate boundaries. With *Seismic Explorer*, students identify patterns from earthquakes locations USGS recorded and volcanic eruptions recorded by the Smithsonian Institution Global Volcanism Program. With *Tectonic Explorer*, students vary conditions such as plate number, location, density, and force dynamics, to simulate the formation of various landforms over hundreds of millions of years on an Earth-like planet.

Introduction

What will Earth look like in 500 million years? The supercontinent of Pangea existed until about 200 million years ago, when plate movement ripped it apart, continuously moving continents into the arrangement we see today. The plates are still moving, all the while causing earthquakes and volcanic eruptions, making this conundrum a surprising way to engage students in learning about plate tectonics. Traditionally, teaching about plate tectonics relies on static illustrations, non-manipulative animations, or hands-on activities using modeling clay to represent Earth's physical layers (crust, mantle, and core). While these methods create visual artifacts, they do not help students develop an understanding of the Earth as a dynamic system, driven by energy from its' interior. Computer-based modeling technologies have the potential to allow students to manipulate aspects of plate tectonic phenomena and to visualize emergent phenomena.

This article describes a free online curriculum module developed by the Concord Consortium and Pennsylvania State University as part of the National Science Foundation-funded project called Geological models for Explorations Of the Dynamic Earth (GEODE).

The GEODE module can be found online at learn.concord.org/geo-platetectonics. Register for a free account and access to pre and posttests and class management plus a student reporting system.

This module, called “What will Earth look like in 500 million years?” (**Figure 1**) uses two web-based tools to help students visualize what takes place both at and below the surface as plates move and interact with each other. First, *Seismic Explorer* is a real-world, data visualization tool students can use to investigate patterns of earthquakes and volcanic eruptions. Second, *Tectonic Explorer* is a 3-dimensional, interactive plate tectonics model with which students can test hypotheses about how motions of plates in different arrangements result in various landforms found on Earth.

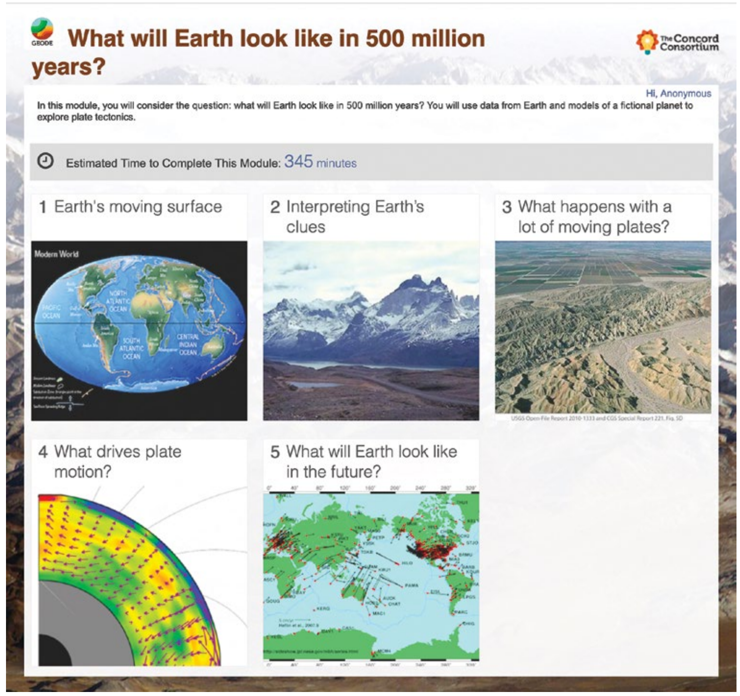


Figure 1. The GEODE module, “What will Earth look like in 500 million years?”

In secondary schools, Earth and Space Science (ESS) is not typically treated as a laboratory science, in part because the phenomena are not amenable to students’ direct observation and investigation. Earth and space science phenomena happen on scales well beyond students’ perception and experience and are hard for them to directly observe and control (Lee, Liu, Price, & Kendall, 2011; Tretter, Jones, & Minogue, 2006). Students typically learn about volcanoes, earthquakes, and the materials that make up the layers of the Earth independently of each other. Connecting geologic features and events to plate motion is often taught by asking students to interpret traditional data that scientists used to develop plate tectonic theory (e.g. fossil record across continents and magnetic seafloor striping); however, this is typically done without mentioning plate interactions as a main causal model (Chin & Brown, 2000). Research on learning progressions related to plate tectonics (McDonald et al., 2019) reveals that (1) students are rarely asked to develop a system-level, mechanistic understanding of plate tectonics; and (2) teaching about plate tectonics based on major historical evidence appears to create conceptual difficulties that hinder students’ development of a system level understanding.

Current modeling technologies can make complex and dynamic systems visible and interactive (Honey & Hilton, 2011). Research shows that computational models provide opportunities for students to interactively explore the behavior of complex systems (Yoon, Goh, & Park, 2018) and that visualizations can improve students learning (Kali & Linn, 2008) in Earth science (Edelson Gordin & Pea, 1999) especially when the modeling instruction is interactive (Pallant & Tinker, 2004). Dynamic models of Earth systems can help students understand the underlying mechanisms and physical processes that shape Earth’s surface. The explicit inclusion of modeling instruction has the potential to support science learning for students by making complex systems manipulative and by making student thinking visible (Brewe et al., 2010).

Thinking Like a Scientist

A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (National Research Council, 2012) advocates the importance of engaging students in science and engineering practices when learning science in the classroom. This focus is grounded in the idea that science teaching should be about students participating in authentic activities (Chinn & Malhotra, 2002) that are “like” what scientists do. However, typical Earth and Space Sciences teaching mostly addresses the historical nature of Earth and its properties, without treating Earth as a dynamic system with many interconnected phenomena. This makes it difficult to create authentic, inquiry-based science activities for students in K-12 classrooms. The GEODE module supports students’ sense-making as they work through a series of investigations of plate tectonics-related phenomena with technology-enhanced data visualization and simulation tools. By bridging modeling and data technologies, the "scientific inquiry" promoted in the GEODE module integrates the Next Generation Science Standards core disciplinary ideas with the scientific practices of modeling and constructing explanations, and also helps students grapple with the cross cutting concept of systems and system models (NGSS Lead States, 2013).

Geoscientists increasingly use technological tools, including computer-intensive models and big data analytics, to understand the complex phenomena they study. If students are to engage in authentic scientific practices, they must carry out investigative science activities in-line with experts' recommendations (National Academies of Sciences Engineering and Medicine, 2019). Technological tools are vital in having students explore data, identify data patterns, and explain data patterns based on their understanding developed from system models. Well-designed technological tools can overcome some of the difficulties inherent in geologic scales of time and space.

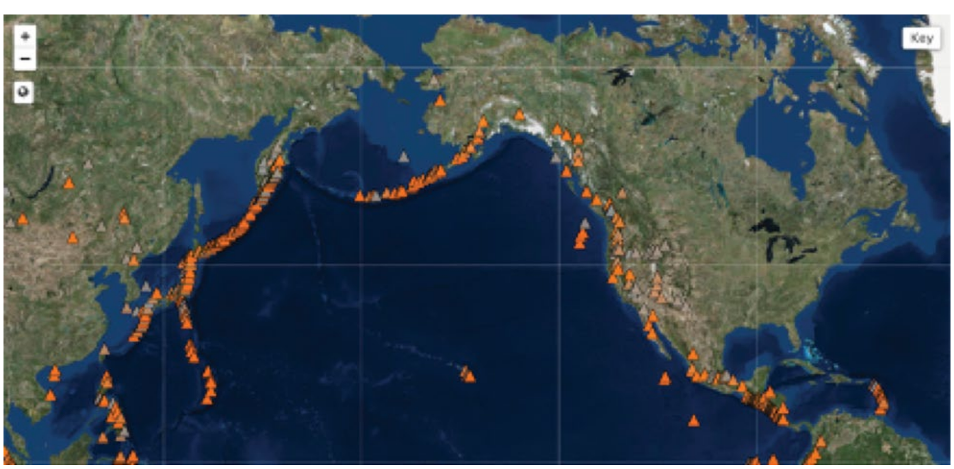
The Curriculum Context

The GEODE module consists of five activities implemented over seven 45-minute class periods. The module focuses on the big idea that the Earth's surface is made up of simultaneously and continuously interacting tectonic plates at all sides of their borders. Students make observations about Earth, using models to test hypotheses, and explain how Earth's system of tectonic plates created and continues to shape geological features and events on Earth.

The module deviates from the common practice of compartmentalized teaching of earthquakes, volcanoes, landforms, and plate tectonics. Instead, it helps students to cross-examine geologic processes, e.g. mountain formation, and events, e.g. volcanic eruptions, through the lens of plate tectonics theory. The intention of this design decision is to support students' formulation of mechanistic explanations about how prominent landforms such as the Himalayas, the Andes, and the Red Sea, have formed near the boundaries of plates. In our curriculum, students make observations about Earth in the present and formulate and test their hypotheses about what caused Earth's surface to be the way it is. The GEODE module is specifically structured to scaffold experiences for students so that they can develop their own explanations from the evidence, investigate phenomena through data representations, and test hypotheses with a simulation that models plate tectonics in action on an Earth-like planet.

In the first activity, students examine real-world data (**Figure 2**) (GPS, earthquake, and volcanic eruption data) to recognize that Earth's surface is broken into many moving pieces (tectonic plates) and that earthquake and volcanic eruption locations can be used to identify boundaries between these pieces.

Figure 2. Volcanic eruption data to help students see distribution patterns evident on Earth's surface.



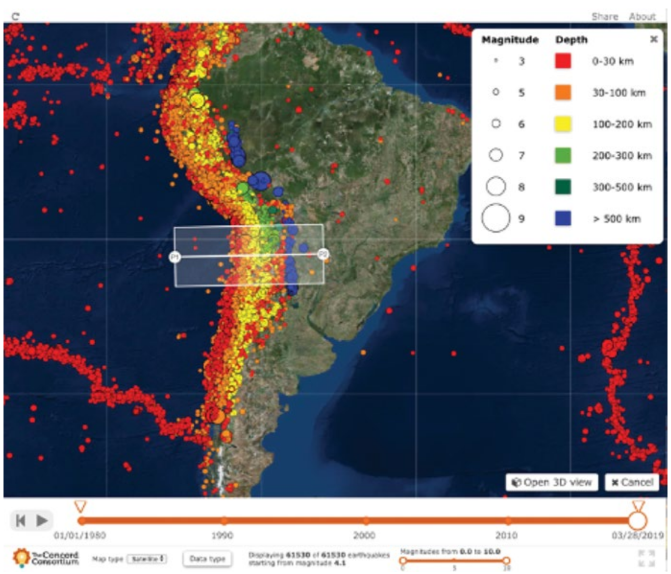
In the second activity, students investigate the distribution of landforms, earthquakes, and volcanic eruptions as consequences of plates moving towards each other at convergent boundaries. Three convergent boundary cases are used: the Andes, the Aleutian Islands, and the Himalayas. In each case study, students examine the elevation profile associated with the landform as well as earthquake and volcanic eruption patterns to develop a hypothesis about what is happening to cause these patterns (**Figure 3**).

Figure 3. Students analyzing earthquake data in Seismic Explorer.

Students then test their initial hypotheses with Tectonic Explorer (see below) to simulate the creation of landforms. In the third activity, students examine the other ways that each of Earth's tectonic plates is interacting with all its surrounding plates. Students explore case studies of divergent boundaries such as the mid-ocean ridge in the Atlantic Ocean and examine how transform boundaries often form the link between the other types of plate boundaries. They also consider how each plate must move as part of a system, interacting with all of the adjacent plates. In the fourth activity, students explore the causal mechanisms and forces that drive plate motion focusing on mantle convection currents, and some consideration of ridge push and slab pull. In the final activity, students synthesize their understandings of all the kinds of plate interactions into a system level explanation about how major geologic landforms and events are the result of the system of moving plates and that these movements can be used as important clues to predict Earth's future.

The GEODE Technology Tools

Seismic Explorer is designed to support the visualization of real-world earthquake, volcanic eruption, and plate motion data. Students use Seismic Explorer to (1) look for patterns in earthquake and volcanic eruption distribution across Earth's surface (**Figure 4a**), (2) examine the relationship among earthquake, volcanic eruption, and landform distributions, and (3) explore cross-sections to investigate earthquake depth patterns (**Figure 4b**).



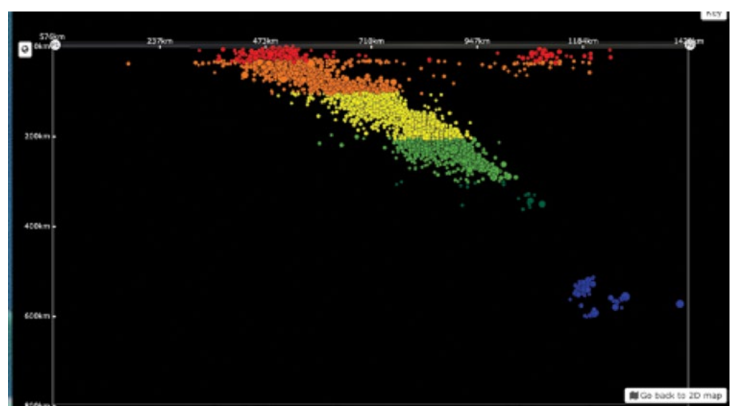


Figure 4a (left). Earthquakes as visualized in Seismic Explorer. The color of circles represents depth while size of circles represents magnitude.

Figure 4b (right). Cross-section along a convergent boundary shows earthquakes following a descending plate.

Tectonic Explorer is a dynamic model of plate interactions on an Earth-like planet. In this web-based three-dimensional simulation of multiple plates, students can change the properties of plates such as density, direction of movement, and locations of plates and continents. By experimenting with this model, students are able to witness plate interactions on a global system level, observe changes over time, and see how interactions of plates result in new landforms. With this model students can set up different initial scenarios and observe the emergent phenomena. An easy-to-use Planet Wizard allows students to choose the number of plates on the planet, draw continents on some or all of the plates, and set motion vectors and relative densities for each plate. Students can then run the model and observe the formation of mountains, ocean trenches, mid-ocean ridges,

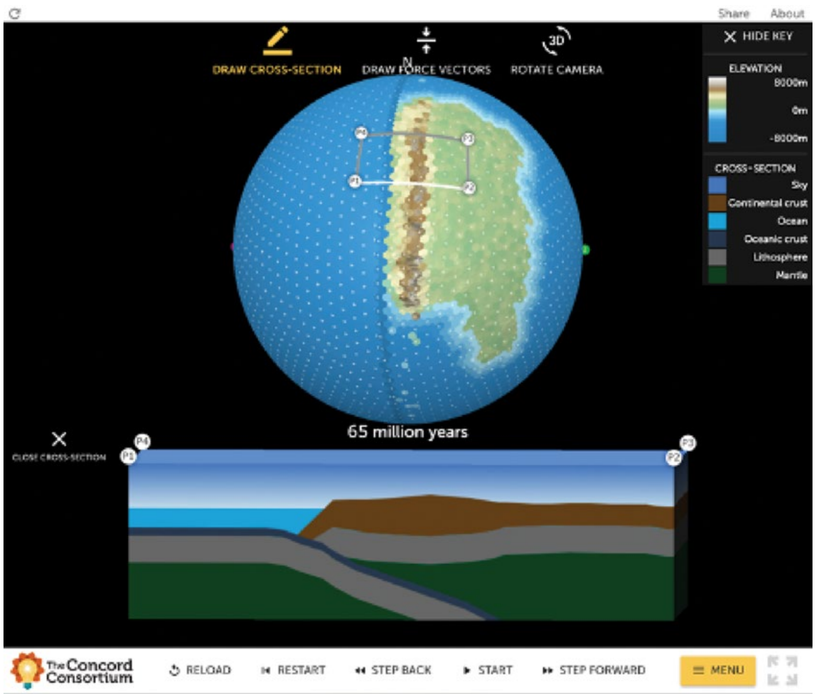


Figure 5. View of a dynamic model along a convergent boundary in an Earth-like planet using Tectonic Explorer. The cross-section shows ocean trench formation and mountains building.

volcanic eruptions, and island arcs (**Figure 5**). They can see supercontinents forming and breaking up and oceans forming and disappearing. To support students thinking across the two tools, Tectonic Explorer also has a feature that allows students to make cross-sections and simultaneously observe sequences of events dynamically changing at and below the surface. Tectonic Explorer's whole plate visualization encourages students to think not only about what is happening in one location on Earth, but also how it might affect what is happening in different locations on the planet. This system view is deeply important in developing students thinking about Earth's entire surface as constantly in motion, even if we can't see it.

In the GEODE module students use these two tools in complementary ways to carry out their investigation. In each case study, students use data gathered from Seismic Explorer, as well as geographic profiles, to develop hypotheses about the nature of the dynamics of the plate system. Students then test their hypotheses with Tectonic Explorer to model the necessary conditions needed to account for the observed phenomena.

The GEODE module is undergoing a series of design studies. In an early study, five teachers implemented the module along with pre- and post-tests in their classes with 159 middle and high school students. Overall the students made significant gains (ES=.62 SD for content understanding) from pre- to post-tests. We are currently field testing our materials with 28 teachers and 1570 students in a wide variety of settings from middle and high schools, suburban, urban, and rural schools, and with a diversity of students. Teacher post-module implementation survey responses indicates the type of thinking and reasoning teachers are witnessing in their students. One teacher told us in a feedback survey that her students discovered "that islands grow out of the ocean floor, that there is land underneath the oceans, and that if two plates are moving towards one another, at some point on earth, they would have to be spreading apart somewhere else." The teacher noted "this is really hard to show in most plate tectonics demos and simulations!" Another student mentioned "well if the plates are moving together on this side, then they have to be moving apart on the other side." This sort of system thinking is rarely seen in secondary school students. These quotes suggest the instructional values associated with data and modeling tools for Earth systems science. Similarly, another student stated "I think the most interesting thing I learned was using the 3D earthquakes model to see how deep earthquakes can go. Before this, I always thought they were near the surface." Another teacher told us she was happy to see her students make connections between earthquakes in the Seismic Explorer and plate subduction in the Tectonic Explorer.

Teaching with GEODE

It may seem like a challenging goal for middle school students to understand the interconnected and dynamic nature of plate tectonics, but evidence from learning progression research (McDonald et al., 2019) suggests that middle school students are capable of developing these sophisticated explanations about Earth's plate systems with proper support. What is often missing in plate tectonics curricula are opportunities for students to engage in investigations designed to link the dynamic nature of surface phenomena and the mechanisms that drive plate motion to real-world data and observations. With technological tools teachers can appropriately elevate their performance expectations for their students when studying plate tectonics. With technologically-enhanced, inquiry-based investigations, the teacher's role changes from directing and lecturing to supporting students in their development of explanations as students analyze, interpret and discuss the data. The tools can provide students with powerful ideas that can build on their existing knowledge and in turn help them reason about scientific phenomena (Kali & Linn, 2008). For teachers these tools can create unique learning environments where all students reason with otherwise inaccessible content. For students to develop sophisticated reasoning from the data and modeling tools, teachers and curricula must support students in identifying and interpreting the patterns in the data and considering possible causes of these patterns. Then students must make connections between each case in the module and the larger guiding question of what Earth will look like in 500 million years. We found that students using our tools were able to articulate how plate motions along convergent, divergent, and transform boundaries explain the patterns of earthquakes, volcanic eruptions, and landform distributions.

Conclusion

The idea that Earth's surface is in constant motion is very engaging. Students will wonder: In 500 million years will Australia collide with Asia? Will the Atlantic Ocean have closed again? Of course, projections into the future are speculative but can nonetheless be scientific conjectures based on GPS data that track how plates are moving in recent years combined with the existing evidence that plates have moved in the past. The GEODE module featured in this paper direct students' attention to using data about these complex interactions in order to develop conceptual models about how Earth's plates may move in the future. In this effort, modeling and data representation technologies can play an important role in engaging students in inquiry-based investigations through which they can develop deep understanding of how complex Earth systems work.

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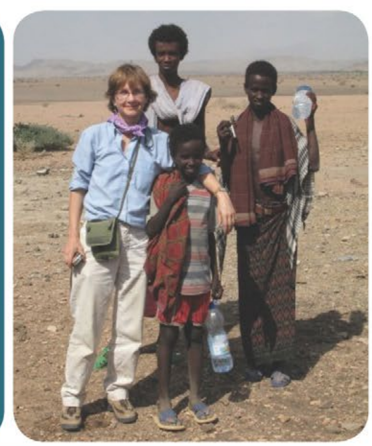

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