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In The Trenches

THE NEWS MAGAZINE OF THE NATIONAL ASSOCIATION OF GEOSCIENCE TEACHERS

Expanding, Advancing the Geoscience Community

In The Trenches

Editor in Chief: Margaret Crowder
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On the Cover: Group photo of participants in Earth Educators Rendezvous 2018 at the University of Kansas in Lawrence, KS. The 2019 Rendezvous in Nashville, TN, co-hosted by Tennessee State University, the largest and only state-funded historically black university in Tennessee, and Vanderbilt University, an internationally recognized research university with strong partnerships among its 10 schools and neighboring institutions, promises to be equally rewarding. [This and the photo on page 1 offered under a Creative Commons Attribution-NonCommercial-ShareAlike license, http://creativecommons.org/licenses/by-nc-sa/3.0/]

In the Trenches **(ISSN 2372-1936)** is a quarterly magazine of the National Association of Geoscience Teachers, a professional association that works to foster improvement in the teaching of the Earth sciences at all levels of instruction, to emphasize the cultural significance of the Earth sciences and to disseminate knowledge in this field to the general public.

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NAGT

IN THIS ISSUE

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A Message from the President of NAGT

"The success of NAGT depends on the efforts of its members. Whether they are serving in one of its many vibrant sections, working in the divisions, or participating on numerous committees, the force of so many people stepping up to volunteer is what supports this organization. That sense of community is what I value most about NAGT."

The Earth Educators' Rendezvous — a concentrated dose of geoscience education and community.

When I first joined NAGT, I did not understand what had to happen behind the scenes to keep the organization running smoothly. In serving as president and as a member of the Executive Committee for the last couple of years it is now obvious how much the success of NAGT depends on the efforts of its members. Whether they are serving in one of its many vibrant sections, working in the divisions, or participating on numerous committees, the force of so many people stepping up to volunteer is what supports this organization. That sense of community is what I value most about NAGT. I see evidence of that when hundreds of like-minded folks show up for the annual Earth Educators' Rendezvous. It is a concentrated dose of geoscience education in just five days. It is always great to participate with colleagues in the workshops, grab new ideas from the teaching demos, learn about new research findings at the talks and poster sessions, and catch up with old and new friends at the social events. I'm looking forward to attending this year's Rendezvous in Nashville, from July 15-19, and I look forward to seeing many of you there. (Come for the geoscience learning, stay for the hot chicken and country music hall of fame!)

This is an exciting time to be a geoscientist. We see evidence for the need of geoscience knowledge all around us, and it brings with it the potential to increase interest and broaden participation in our science. At the same time the nature of technology and the role of science in society is changing, creating new jobs for our graduates that didn't exist a decade ago. We can no longer just teach the same classes over and over again. We need to think about innovations and adaptations we can make to support our students as we prepare them for a rapidly evolving workforce. NAGT provides forums to discuss how we shape these new learning environments through meetings like the Rendezvous and other professional development programming and through membership-benefit publications like *In the Trenches* and the *Journal of Geoscience Education*.

Thanks for your support if you are already a member of NAGT. If you are not a member, why not join your friends and colleagues and become a part of the NAGT community today. More information on membership can be found at https://nagt.org/nagt/membership/index.html.

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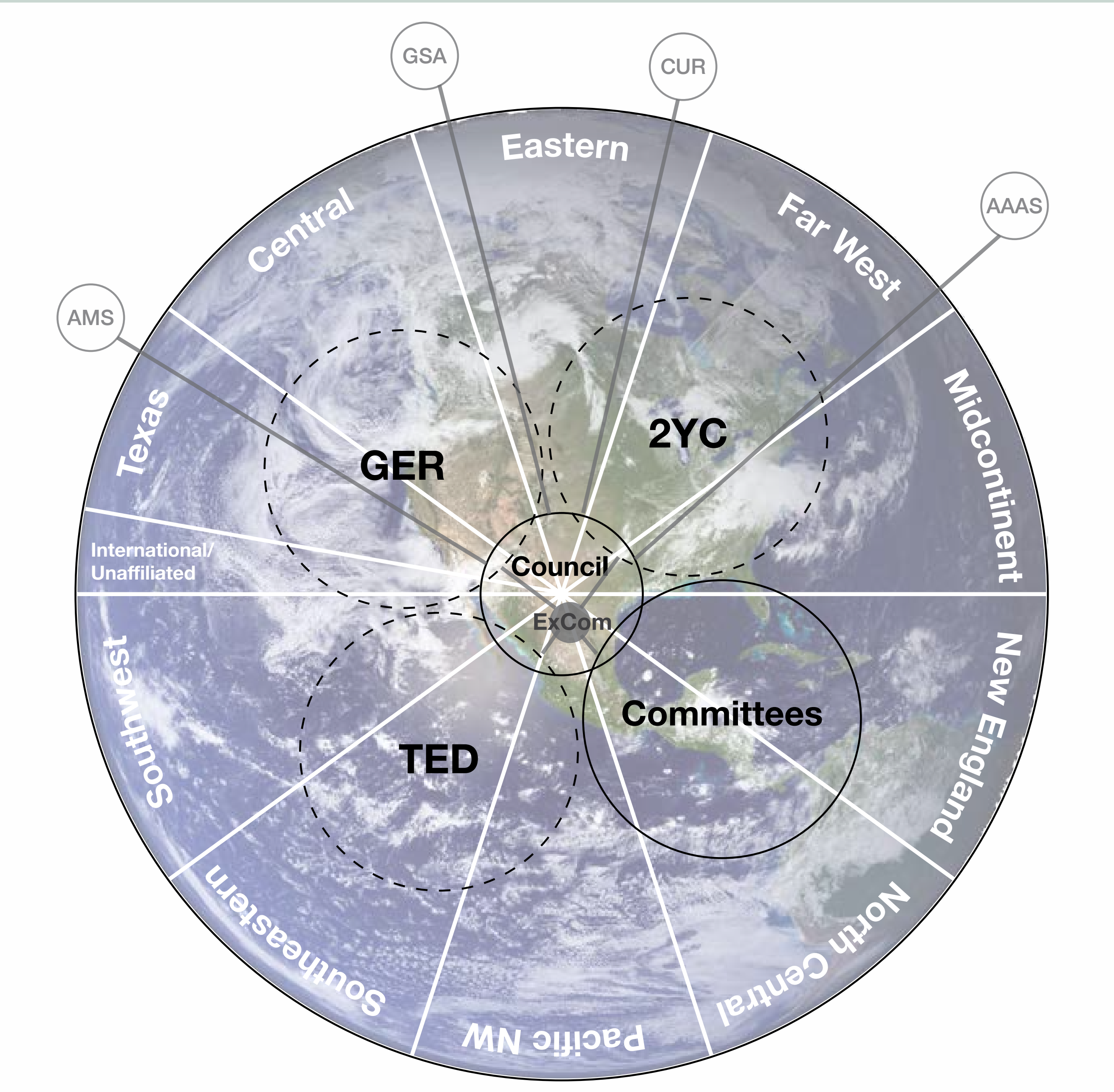
Understanding NAGT: Members and Leadership

I joined NAGT as a graduate student almost 20 years ago. At the time, how the organization was structured never entered my thoughts. However, now having served in the presidential line, on committees as both member and chair, and as editor of the *Journal of Geoscience Education*, I know that organizational activities don't happen automatically. A functioning not-for-profit professional association relies on its members and a strong organizational structure that supports members, values their contributions, and provides pathways to leadership. Knowing more about the structure can help everyone contribute to and benefit from NAGT.

The large circle with the globe (below) represents the membership of NAGT. The white lines divide the globe into sections: most NAGT members are also members of regional sections based on their location—there are no extra fees for being part of



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To explore all the resources NAGT offers educators, visit https://nagt.org.

a section. The smaller circles with dashed lines are the interest-based divisions—the Geoscience Education Research Division, Two-Year College Division, and Teacher Education Division—which members can choose to join for an additional fee. Sections and divisions both elect their leadership and can organize meetings, sponsor workshops or sessions, produce a newsletter, give awards, etc.

NAGT also has committees that do an enormous amount of work for the national organization: award committees, professional development and website committees, advocacy and diversity committees, and others. These all draw from the membership—members can volunteer to serve on committees or be nominated by other members. Some members of committees are determined *ex officio* and others are appointed, usually by the Executive Committee.

To facilitate collaboration, NAGT appoints liaisons to associations like the Geological Society of America, the Council on Undergraduate Research, and several other external groups.

At the center of the globe are the NAGT Council and the Executive Committee (ExCom). The leadership of each section and division and liaisons make up the NAGT Council, which provides (1) a forum for sections and divisions to learn from and work with each other and (2) a means for the interests and concerns of the membership to reach the Executive Committee. The Council serves in an advisory role to the ExCom and is not a voting body within NAGT.

The Executive Committee is the leadership of the national organization. It consists of officers elected by the membership (councilors-at-large, vice presidents, and a secretary/treasurer) and three that are appointed (the executive director and the editors of the society's journals). Members of the ExCom serve as liaisons to the divisions and sections, and often serve on committees as *ex officio* members. The executive director and the whole society are supported by the often behind-the-scenes work of the Executive Office.

Though it might seem complex, this structure allows NAGT to support a diverse, inclusive, and thriving community of educators and education researchers. There are many avenues for members to get involved in leadership roles and to bring their questions, concerns, and interests to the national leadership. You can read about all of the ways to get involved on the NAGT website (https://nagt.org/nagt/about/involved.html).

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Supporting the Success of All Students

Now is an opportune moment for the Earth and environmental sciences to adjust our modes of attracting and educating students. National demographics are changing (Bernard & Cooperdock, 2018), our science and society need diverse geoscientists (Huntoon, Tanenbaum, & Hodges, 2015), and our professional ethics demand equitable educational opportunities for all. We have the responsibility to make choices in our teaching and in our programs to better attract and support a diverse population of students (Callahan et al., 2017; Sherman-Morris & McNeal, 2016; Wolfe & Riggs, 2017) and to remain a thriving and relevant scientific community poised to meet the needs of society.

Workshop Overview

The National Association of Geoscience Teachers (NAGT), with InTeGrate support, offered a workshop April 10-12, 2019, at the University of Illinois at Chicago, titled "Diversity, Equity, and Inclusion in the Earth and Environmental Sciences: Supporting the Success of All Students." Sessions focused on students from traditionally under-reached and under-supported groups, including students from ethnically and culturally diverse backgrounds and students with physical, mental-health, and learning needs. Participants and leaders drew from our collective experiences, the science and sociology literature on inclusion and equity, InTeGrate modules, NAGT's Traveling Workshops Program, SAGE 2YC resources (Macdonald et al., 2019), and recent publications in the *Journal of Geoscience Education*. The 48 participants came to the workshop from a broad distribution of institutional types: two-year colleges (19%) and four-year undergraduate (48%), masters-granting (8%), and doctoral (23%) institutions. Thirty percent of faculty taught at Minority Serving Institutions. Participants left the workshop with action plans to be implemented in their classes on immediate to longer-term timescales and with new ideas to discuss with their programs.

The overarching goals of the workshop were for participants to: 1) discuss diversity, equity, and inclusion and how they strengthen the Earth and environmental sciences; 2) recognize barriers to and opportunities for inclusion; 3) explore strategies and practices that attract students, cultivate their science identities, and help them to thrive in college and beyond; 4) apply a framework of engagement, capacity, and continuity to program evaluation and design; 5) develop an action plan with strategies to strengthen diversity, equity, and inclusion at course and program levels; and 6) enable networking, sharing, and collaboration within the Earth education community to improve diversity, equity, and inclusion. Participants considered the challenges and barriers undergraduate students encounter and explored a range of approaches to broaden participation and foster inclusion. At the department level, we discussed program evaluation and design (Jolly et al., 2004); at the curricular level, course offerings and their topics; and at the course level, inclusive teaching strategies. The program was designed to model and share teaching and engagement practices related to workshop goals and included pre-workshop readings, a mix of interactive plenary and breakout sessions, and time for reflection and action planning.

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Rachel Beane leads a session on building students' science identity. [Photo by Mitchell Awalt]

Sessions

The workshop consisted of a mix of breakout and plenary sessions. Breakout sessions clustered around three themes: 1) supporting access, inclusion, diversity and in degree programs, 2) developing a curriculum to support all students, and 3) teaching strategies for the inclusive classroom. The first plenary session, "Building Students' Science Identity," highlighted strategies to infuse career information and diverse perspectives into courses and to build students' abilities to perceive of themselves as future scientists (Flowers & Banda, 2016; Schinske et al., 2015). Two other plenary sessions focused on issues related to inclusion: "A Psychologist's Perspective" focused on recognizing the influence of unconscious bias and how to work towards uncovering it, and "Why Inclusivity Matters" focused on positive effects of diversity such as allowing the exploration of more complex issues and questions that commonly occur in areas populated by segments of society not typically represented in the discipline. The "Growing Student Strengths" session applied the context diversity model of Ibarra (2001) towards developing diverse approaches to learning. [Words missing?] The "Building a Sense of Community" plenary session a model of engagement, capacity, and continuity (Jolly et al., 2004) to program assessment and design. During the final session, participants shared a portion of the action plan they developed and received feedback.

At the workshop's conclusion, participants expressed appreciation for the opportunity to come together to discuss issues and share strategies and indicated that they would make changes in their own teaching and bring ideas back to their programs. One participant appreciated "Learning about specific actionable items for increasing inclusion, developing science identity in students, and continuity...and having the space and time to start to work on an action plan." Another participant noted, "I will be more pro-active about incorporating intentional and directed activities, behaviors, curriculum, opportunities, and attitudes that specifically support inclusive and diverse student relationships." The workshop website has the complete program with related resources, suggested strategies, and collective ideas: https://serc.carleton.edu/215951.

The Traveling Workshops Program

This workshop was part of the NAGT Traveling Workshops Program (TWP) (https://nagt.org/nagt/profdev/twp). While this was a national workshop hosted by TWP, more commonly institutions, departments, or organizations will apply for and sponsor a TWP. Typically, two TWP facilitators will travel to the institution to lead discussions and action planning. Workshop options include: Supporting the Success of All Students, Building Stronger Geoscience and Environmental Science Departments, Strengthening Your Cross-campus Environmental and Sustainability Programs, Strengthening Your Intro or Upper-Division Course, and Making Your Course More Effective and Societally Relevant.

Acknowledgments

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Continued on Page 6 >

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(Above) Each year, NAGT recognizes dozens of Outstanding Earth Science Teachers. If you are a K-12 educator, you could be one of them.

Community Science Education: A Personal Journey

The message of this article is simple: it is important and worthwhile to teach geoscience through real-world projects that bring you and your students into close collaboration with local community leaders. I'll call this approach community science education: science education that accompanies and supports a sustained partnership with local community leaders and uses science to tackle community priorities. My experience shows that these kinds of projects make a real difference, engage students, allow you to follow best practices in science education, and can be powerful ways to diversify the sciences.

These projects aren't without challenges, though: current education systems weren't built for this approach and few of us have been well-prepared for this work. However, this kind of science and science education is important and potentially transformational—it can help students learn, communities thrive, science innovate, and in the geosciences it can help us deal with pressing global issues like climate change. I'd like to share some tips for how to do community science education. I'll situate all this in the context of my own experience and some of the existential crises that prompted my conversion to community science.

One of my formative experiences with community science education occurred when I was a new assistant professor at West Chester University in Pennsylvania. West Chester taught future teachers and the geoscience faculty were committed to modeling good teaching strategies—it was one of the things that attracted me to the school. I expressed an interest in project-based learning and was connected to Zulene Mayfield, who led a group working to fight a plan to open medical and industrial waste incinerators in her city of Chester, PA. Chester was a predominantly African-American community and many residents had fewer financial resources. Ms. Mayfield asked if my students and I could work with her and her neighbors to estimate the potential danger from the incinerators. I answered, regretfully, that I was looking for a project that provided more opportunities to learn the fundamental theoretical concepts in meteorology. Ms. Mayfield replied, "Young man, if your science is only theoretical, why do it?"

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Lessons about Community Science Education

My interaction with Ms. Mayfield taught me two important lessons about community science education. The first was: ***you must adapt your curriculum to match local priorities.*** Good community science comes from meeting local leaders, listening to what they want to accomplish, and finding ways to work together on that. (Ms. Mayfield was able to find another professor to work with that year, I'm glad to say; I took her comment to heart and worked with my students the next year to design a class around an issue important to their families—flooding.)

It may require some thinking on your part to connect community priorities to educational goals. This usually isn't that hard, however. The Next Generation Science Standards (NGSS) emphasize three things: cross-cutting concepts, science and engineering practices, and disciplinary expertise. Any community priority presents an opportunity to explore cross-cutting concepts (patterns, cause and effect, systems and system models) or teach science and engineering practices. We are lucky in the geosciences: interaction with the Earth relates to many community priorities. For instance, in a recent project that was part of Earth Connections, a program which focuses community science education in the geosciences, an Atlanta neighborhood's desire for local improvement was advanced by focusing on rehabilitating a damaged local stream.

A good resource for navigating connections between science and communities is the *Scientist-Community Partnerships Guide* from the Union of Concerned Scientists. Resources with a tighter focus on science education include an excellent workbook for informal science educators, *Partnerships for Impact,* and a great article called "Place-Based Education: Connecting to STEM Learning Experiences." These three online resources [see RESOURCES at end for URLs] provide practical tips and sample case-studies that you can use to help with connecting, building relationships, and designing STEM educational projects with community leaders.

The second lesson I took from the conversation with Ms. Mayfield was: ***you must prepare yourself, and***

your students, to navigate the boundaries of science and action. Part of what I was saying to Ms. Mayfield back then was that I didn't know how to be practical. In order to work on community science education projects, I had to learn how to translate science into action. That meant realizing that some scientific skills—like project management, communication, teamwork, and project management—also worked in more concrete contexts. It also meant developing new skills, like learning about the boundary between advocacy and advising and deciding how to approach that boundary. A book I've found super-helpful for thinking about this *The Honest Broker* by Roger Pielke Jr.

The Purposes of Diversity

I had a second formative experience when I led a program to address the historical lack of diversity in the geosciences. We invited talented college students of color to a national laboratory to work with our scientists on cutting-edge research projects. One of the students asked if he could work on a project on tribal lands. Our laboratory didn't have a single project on tribal lands or working with tribal communities. (We were able to find a scientist from another lab who was doing work with indigenous communities in the Southwest and matched our student with her. Since then, our student has finished his PhD and now serves as a tribal science liaison in a federal agency.)

This episode called into question the point of diversity. Was diversity in science something we did for the sake of scientific demographics or did it have a larger purpose? Could diversity also be an opportunity to ask new kinds of scientific questions, develop new scientific methods, and benefit new communities? And if we wanted to frame our diversity-in-science efforts in that larger context, what would that look like? An excellent paper for thinking critically about what we mean by equity and what we seek to accomplish with equity in science education is "Everyday Science Learning and Equity: Mapping the Contested Terrain" [Philip and Azevedo, 2017].

To me, community science education seems like one answer to these questions. **Community science offers a unique opportunity to advance equity in science education.** Because it is place-based, it doesn't pull students away from their roots and their support networks. Because it begins with community priorities, it doesn't force students to choose between service to their community and advancement in science. Because it is done in collaboration with community leaders, it welcomes and celebrates community knowledge and culture, instead of implying, however unintentionally, that community knowledge is less important than scientific knowledge.

About three years after this student's question, I had the opportunity to test-drive community science education in that same internship program. I arranged for two interns to spend several weeks living in a Louisiana community that was rapidly losing land from a litany of environmental issues: the rerouting of the Mississippi, deforestation, canals cut for oil and gas pipelines, invasive species, and sea-level rise due to climate change. Their assignment for those weeks was to get to know the community and design a project—with community leaders—that used Earth science to advance community priorities.

The students were supported by Earth scientists, but they were also supported by two anthropologists who were experts in community science work. In fact, one of the anthropologists had used her PhD research to explore how to help scientists learn community science. She met with the students every night to talk about what they had learned, what went well, what they struggled with, and how they wanted to approach the next day. She helped them record and revisit the things they learned and look for patterns. She helped them explore what they were learning about the community and what they were learning about themselves. Because of her guidance, the students were able to build identities as scientists, community partners, listeners, and experts with something to offer. They became friends with each other, with their mentor, and with members of the community; those friendships persist to this day.

What I learned from this, more than anything, is that **community science education requires you to embrace social aspects of science learning**. While this is hardly surprising, it goes way beyond the kind of group-work we might see in a typical classroom. I find it helpful to explicitly call out the social nature of learning, the intersection of identities, and ask students to attend as carefully to each other's learning as to their own. You can support students through team discussions, reflective journaling, online discussions, peer mentoring, peer-problem solving, and reflections on cultural practices. A nice introduction to this useful way of thinking about learning, especially in the context of community science, is available in Chapter 4 of *Learning Through Citizen Science: Enhancing Opportunities by Design* [see RESOURCES for URL].

Changing the Science Education System

The final existential crisis I'll share isn't my own; it is a true story that someone shared with me. It is about a young man in graduate school and his annual visits home. In each visit, his grandmother asks him to share what he's learning in graduate school. Every year, he tells his grandmother what he is learning, and she tells him to go back to school and continue his work. Because his work is getting more and more technical, each year he struggles a little more to explain it. Finally, he tells his grandmother he just can't. "Grandmother," he says, "there are words we use in graduate school that can't even be translated into our language." "Don't go back to school," his grandmother answers. "If what you are learning can't be translated into our language, how can it be useful to our people?"

What that story says to me about community science education has changed over the years. At first it was a simple call for the need to do more relevant research or an even simpler call for better science communication. Then it became about the lack of access to science and science education in some communities, especially communities of color. It also spoke to me about the need to reframe outreach not in terms of telling communities about scientific discovery, but in terms of engaging communities around their own priorities. It was a short walk from there to thinking the story's key lesson is the importance of asset-based approaches to science education. What if his local and community knowledge was the foundation for his work in graduate school, instead of something ignored?

Right now, while that story still contains all those meanings, the meaning that most resonates with me is that our system of science education isn't well-suited to community-based approaches. The science education system doesn't help or encourage students to connect with their communities. It doesn't educate our teachers in how to engage with communities, it doesn't orient our curriculum around local priorities, it doesn't enable the kind of cross-disciplinary teams necessary to solve local challenges, and it doesn't promote the kind of cultural competence we need to attend to the issues of equity inherent in many community issues.

That story makes me want to change the system. And to ask for your help. I'm working on changing the system through my job at AGU's Thriving Earth Exchange, which advances community science by helping launch and celebrate science projects that are rooted in local priorities. While we have lots of college and graduate students involved, we aren't doing as much as we could in K-12 education.

I hope the journey of my thinking about community science convinces you, as a science educator, to try community science education, and inspires a few ideas for getting started. Please do and please let me know how it goes. Together, we can change the system and make community science a regular part of science education.

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Place-Based Education: Connecting to STEM Learning Experiences. Available at http://csl.nsta.org/2018/09/place-based-education/.

Scientist-Community Partnerships: A Scientist's Guide to Successful Collaboration. Available at https://www.ucsusa.org/center-science-and-democracy/connecting-scientists-and-communities/scientist-community-partnerships.

You can learn more about Earth Connections at https://serc.carleton.edu/earthconnections/index.html. More details about the Atlanta project are available https://serc.carleton.edu/earthconnections/regional_alliances/atlanta.html.

Learn more about Thriving Earth Exchange at www.thrivingearthexchange.org.

Flyover Country: Creating Flexible Field Experiences Using a Mobile Geoscience App

Overview

Field experiences are an integral and formative part of undergraduate education in the geosciences (Petcovic et al., 2014; Wilson, 2017). However, many students have obligations that restrict their availability to attend instructor-led field trips outside of scheduled class time. These constraints on students' time, including family care, paid work, and contributions to family businesses, tend to be more limiting for underrepresented, low-income, and first-generation students (Warburton et al., 2001), presenting a barrier to early exposure field experiences that may lead them into the geosciences and encourage them to persist into higher level coursework (Levine et al., 2007; Wolfe, 2018). Mobile apps can be used to overcome barriers by facilitating self-guided field trips, which give students the flexibility to take field trips on their own schedules. Flyover Country is a free National Science Foundation-funded mobile app developed at the University of Minnesota that provides users with the ability to access numerous geoscience databases (e.g., Macrostrat geologic map database, Paleobiology Database, Neotoma Paleoecology Database, Open Core Data), Wikipedia articles, and field trip guides along a selected path anywhere in the world. Instructors can use published field guides stored in the app as well as upload novel guides for students to download so that they can lead themselves on field trips. This functionality was demonstrated at Earth Educator Rendezvous field trips in 2017 and 2018.

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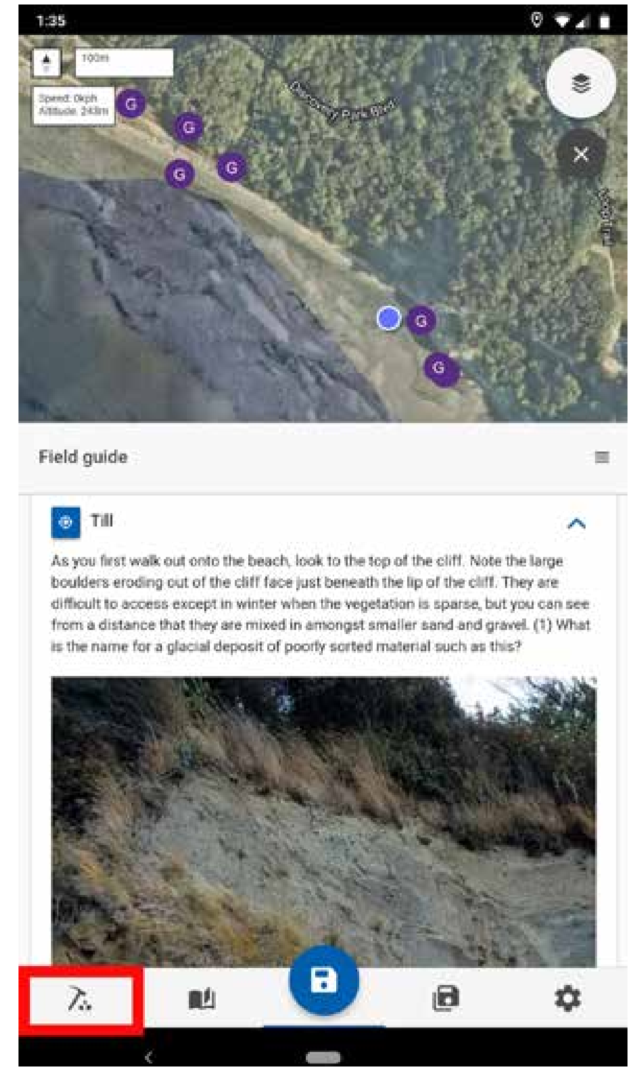
Flyover Country fills a niche where organized field trips are difficult due to student or instructor limitations on time, transportation, etc. While virtual field trips are often used to fill this need and can offer rigorous and engaging experiences (Tuthill and Klemm, 2002), self-guided, Flyover Country-facilitated field trips differ as students still visit sites in person. Since students are physically present at sites, instructors may ask students to collect samples (such as sediment), compare samples from different locations, or have other hands-on experiences not available on virtual trips (Hurst, 1998; Arrowsmith et al., 2005). Additionally, students using the app for self-guided field trips report serendipitous positive experiences learning about their local areas and seeing wildlife and other natural phenomena.

Instructor Uses

Instructors interested in using an uploaded field guide can explore existing trips in the "field trips" tab of the app (see photo at right). Alternatively, instructors who wish to enter a field guide for their own local area can go to http://z.umn.edu/fcfg, create an account, and follow instructions for uploading content. Through the field trip content submission portal, users can upload field trip stops as geolocated points, lines, or polygons, as GPS coordinates, or using an interactive map interface. Instructors can also add text, images, and figures associated with each location or field trip stop and provide questions for the student to answer at each stop. Users then submit their field trip guides for editorial approval by the Flyover Country team to ensure the uploaded content is appropriate before they are made available in the open field trip guide database maintained by Flyover Country. Uploading a field trip makes it publicly accessible to everyone using the app and preserves it digitally for future students and enthusiasts to discover; field guides uploaded to the database are also accessible to through http://api.flyover.umn.edu/v2/guide.

Student Uses

Students select a field trip guide by loading a path using two or more points on the map interface, by entering a destination, or from a list of guides. A selected field guide expands to show the guide's stops on the map, layered with information from various geoscience databases. Text and images associated with stops are displayed as part of a pull-up menu from the base of the interface. Flyover Country uses the phone's built-in GPS, allowing students to independently lead themselves through the geolocated stops. As cellular data and wireless Internet connections are not always available, the included geoscience data and field trips can be saved for offline use.



Screenshot of the Flyover Country field guide interface, which is accessed through the tab highlighted by the red box (lower left). Stop locations are indicated on the map by the purple dots with "G," with the lower half showing text and figures associated with the selected field guide stop entitled "Till." A blue location dot marks the user's current GPS-determined location. [Image provided by Shane Loeffler.]

Our Experience

Flyover Country-facilitated field trips were implemented at the University of Washington–Bothell for introductory geology classes beginning in Spring 2017. Course field trips include a tour of downtown building stones and glacial landscapes within nearby public parks. Students are given the option of attending a typical weekend field trip with the instructor or taking the same trip on their own time through the app. Most students who used Flyover Country reported that time conflicts (e.g., work schedules, extracurricular activities, family responsibilities) were the primary reason they chose to take the independent Flyover Country trip rather than attending in person.

Using surveys and comparison of field trip lab scores, we find no apparent difference in lab scores between independent and instructor-led trips. Additionally, post-lab surveys included an open writing section to detail what the students thought was "the most interesting, useful, or enjoyable" part of the experience. The majority of students in both the in-person and app-based groups described additional beneficial outcomes that were not directly content based, such as being outside, seeing things from a new perspective, and visiting nearby locations they had not experienced before. Utilizing Flyover Country in the course curriculum provided students with field experiences that institutional or personal barriers might have otherwise prevented.

In addition to facilitating independent field trips, Flyover Country is used to supplement supervised field experiences. The University of Minnesota Department of Earth Sciences used the app on undergraduate week-long field trips as well as in a hydrogeology course field trip in 2017. During these trips, students travel to geologically interesting areas but limitations on time restrict the number of possible stops. Using Flyover Country, students learn more about the area by selecting and reading about nearby points of interest that are visible during the trip but are not designated stops. Incorporating these points of interest provides students with additional information and a broader context for the region through which they are traveling. This same method of viewing surface geology remotely using geologic maps and satellite imagery coupled with selecting sites for further reading can be used for self-guided virtual field trips which could serve as alternative opportunities for schools or students that would otherwise be unable to visit field localities in person, and can increase access for students who would benefit from written as well as spoken information at field trip stops.

Flyover Country links together GPS, field guides, and open geoscience databases into an offline handheld platform which provides students with the opportunity to independently navigate field experiences. This technology enhances instructor-led field trips and enables students to overcome barriers and participate in a crucial aspect of geoscience education, seeing geology in the field.

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MY FAVORITE DEMONSTRATION

Classroom Demonstrations for the Earth Sciences: Silicate Mineral Structures

The Earth's crust is around 75% oxygen and silicon, and silicate minerals (consisting of those two elements plus a smattering of other ions) are by far the most abundant minerals in the crust. Silicates like olivine (Figure 1) have a wide variety of crystal structures, all based on the silica tetrahedron, which is a complex ion shaped like a four-sided pyramid, with four oxygen atoms at the corners and a silicon atom at the center, During my classroom discussion of this structure, I pass around two different examples of tetrahedra: Dungeons and Dragons dice (Figure 2) that I find at various stores in town, available in a variety of shapes, many of which correspond to crystal shapes, and a back massage device (Figure 3) that I found at a yard sale. This is useful because I also point out that the wooden balls correspond to oxygen atoms, and the silicon atom would be at the center where the steel bars cross. (Incidentally, these feel great on your back if you can find one!)

Fig. 1: Olivine crystal from Pakistan. [Photo by Rob Lavinsky, iRocks.com, made available by CC-BY-SA-3.0, https://commons.wikimedia.org/w/index.php?curid=10430042]

Individual tetrahedra (isolated tetrahedra), as represented by these initial two models, are found in such minerals as olivine. I point out that these negatively charged complex ions are held together with positive metal ions in between the tetrahedra and that the corners of some of the tetrahedra are very close to each other.

Other ways in which silica tetrahedra are organized in silicate minerals are more complex and involve joining tetrahedra together. For these examples, I use a model that originated with a gift my sister gave me several years ago. This construction set consists of twenty-eight ~0.5 steel balls and forty-two ~1" plastic rods with powerful rare-earth magnets at the ends (Figure 4). [Go to the online extras—see the table of contents page for instructions—for information on ordering these types of construction sets.]

Using parts from the construction set, I start with the construction of multiple single tetrahedra (Figure 5). I then join several of them in front of the students by removing steel balls from some corners and "polymerizing" the tetrahedra together to form single chains (Figure 6). I discuss how this forms "single chain silicates" (the pyroxene group of minerals). From there, I bring two chains together to form a "double chain silicate" (the amphibole group of minerals) (Figure 7). Unfortunately, I don't have enough of these rods and balls to create "sheet" (mica and clay) or "framework" (quartz and feldspars) silicates, but with enough balls and rods, these could be made as well.

I'm a strong believer in the idea that if you can draw something accurately, you'll be well on the way to understanding it, and while I make these models, I also draw them on the board so that the students can see what's happening. I encourage the students to draw the structures themselves. These models and the drawings together go a long way to helping the students understand the structure of these typical silicate structures.

This magnetic ball-and-rod construction kit could undoubtedly be used to model other mineral structures as well, as these structures are easier to manipulate and

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Fig. 2: Dungeons and Dragons dice. Tetrahedra are in the bottom row of dice. Knife included for scale. {All photos by Greg Mead]

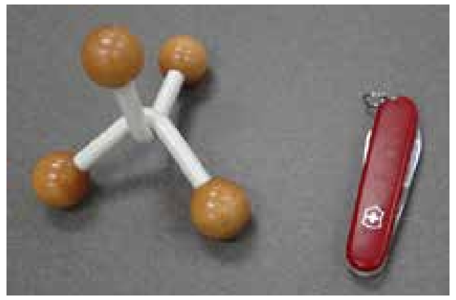

Fig. 3: Original use: back massages

Figure 4: Top left: 6 bars, 4 balls (held together magnetically)

Fig. 5: Arrangement of steel balls and magnetic rods into tetrahedra in the arrangement of Isolated Tetrahedron Silicates (Olivine)

Fig. 6: Arrangement of tetrahedra into Single Chain Tetrahedron Silicate (Pyroxene)

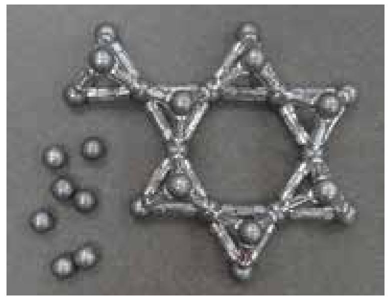

Fig. 7: Arrangement of tetrahedra into Double Chain Tetrahedron Silicates (Amphibole)

In The Trenches

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