

THE EARTH SCIENTIST

~ NESTA - Celebrating 30 Years ~



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SPECIAL ISSUE

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Free Inside
"CHANGING EARTH"
Poster from HHMI

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This image was taken by Jay Brooks in Arches National Park, Utah, in July 2011 while on photography trip. In Utah, July is the monsoon season and rain storms can create interesting cloud formations and lightning. "This particular evening we had some very powerful lightning activity. Shortly after this shot was taken we were running for cover as the storm moved directly over us. We could feel the electric charge in the air and it was a bit scary." This image was shot from a tripod with a Canon 7D, at 24mm, ISO 160, .4 sec, F10, with a Canon 24 to 105 L lens.

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NESTA'S MISSION

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

NESTA Contacts

EXECUTIVE BOARD

President

Missy Holzer
mholzer@monmouth.com

President-Elect

Michael J Passow
michael@earth2class.org

Secretary

Jenelle Hopkins
jhopkins@interact.ccsd.net

Treasurer

Howard Dimmick
dimmick@esteacher.org

Past-President

Ardis Herrold
amacio@comcast.net

Board of Directors Representative

Eddie Cohen
ecohen@pway.org

Executive Director and Association Contact

Dr. Roberta Johnson
rmjohnsn@gmail.com

NESTA Webmaster

Julia Genyuk
jgenyuk@windows2universe.org

NESTA Administrator

Marlene DiMarco
Phone: 720-982-8349
[Contact the Administrator for address for Large Mailings]

NESTA Address:
PO Box 20854
Boulder, CO 80308-3854
Visit the NESTA website at
<http://www.nestanet.org>

FROM THE PRESIDENT

by Missy Holzer, NESTA President, 2012-2014

No Earth & Space Science Teacher Left Inside

We've all heard of the campaign for "no child left inside" and agree there are many benefits from experiencing nature. *Last Child in the Woods*, first written in 2005 by Richard Louv, served as the foundation for the arguments in this campaign, and provides numerous suggestions on what families can do to disconnect from technology and venture outside into our natural world. The 2008 edition of Louv's book and his website (<http://richardlouv.com/books/nature-principle/field-guide/>) even contain a "Field Guide to the New Nature Movement", with simple and practical methods for "saving our children from nature-deficit disorder." (Note: the nature deficit disorder has not been classified as a medical disorder.) Louv's most recent book *The Nature Principle: Human Restoration and the End of Nature-Deficit Disorder* (2011) turns the focus from children to adults and is "...about the power of living in nature—not with it..." (pg. 5) As Earth and space science teachers we have known this power since we made the decision to be Earth and space science teachers.

Leaving our hectic school days behind, summers offer us so much potential to recharge as a person, as well as well as a professional. This summer, how about if we all try to live by the motto of "No Earth & Space Science Teacher Left Inside" and embark on a personal journey into the world about which we teach? Louv (2011) provides an extensive list of physical, mental, and social benefits to be gained from connecting or reconnecting with nature, but for those of us who are passionate about our subject areas, we only need to be reminded why we selected this domain over any other domain – our love of the natural world and how it works. However, when was the last time you took the time to get outside, by yourself, to observe, explore, and reflect as you had done in the past? If you can remember the last time you enjoyed the outside world, then you already live by the motto, but if your response has you scratching your head trying to remember when the last time was, then here are few simple things you can do this summer to personally reconnect with your domain.

Many of us have easy access to the natural world comprising each of the domains of Earth science, including the night sky, our atmosphere, our local geology, and our oceans and coasts. This access makes it easy for us to observe and explore, and otherwise engage with the outside world. Connecting with astronomy may, over the course of one evening, include simple activities such as looking up and watching the movement of a constellation or planet, or it may include grabbing a lawn chair and watching the Perseid meteor shower in August. While going for a walk or bike ride, a glance at the sky and feeling the direction of the breeze reminds us of how weather events form and migrate. Picking up a rock, tending the soil in our gardens, or considering the origin of that hill that challenges our walk, run, or bike ride reminds us of how the local geology is a part of life. For those living near ocean or lake coastlines, a walk along the shore reveals the energy of the water as it changes the shapes of our coastlines one sand grain at a time. While outside observing, exploring, and reflecting, the natural interactions among the atmosphere, geosphere, hydrosphere, and biosphere become apparent. Conceptualizing these interactions adds depth to our experiences and finds us "living in nature."

Within Richard Louv's "Field Guide to the New Nature Movement" you can find other ways to connect and reconnect with the outside world, some of which may turn into new habits. Take time this summer to get outside, and encourage your fellow Earth and space science teachers to get outside, too, so that they are not left inside. Research has identified the benefits of getting

children outside, and guaranteed, adults can be the recipients of the benefits, too. Enjoy your summer and the fall will see you recharged and reconnected.

Louv, Richard. (2011) *The Nature Principle: Human Restoration and the End of Nature-Deficit Disorder*. Algonquin Books.

Louv, Richard. (2005) *Last Child in the Woods: Saving Our Children from Nature-Deficit Disorder* (Paperback edition). Algonquin Books.

FROM THE EXECUTIVE DIRECTOR

At our NESTA conference events in San Antonio Thursday through Saturday, April 11-13, NESTA offered or hosted 16 events including four Share-a-Thons, five topical workshops, our Rock and Mineral Raffle, the NESTA VIP Breakfast, the NESTA Earth and Space Science Lunchtime Lecture, the AGU Lecture, and the NESTA Friends of Earth Science Reception, as well as our Board Meeting and our Annual Membership meeting. With over 1100 participants, our events were well attended, and we had record participation in financial support from our event sponsors, for which we are extremely grateful.

Program Sponsors - We would particularly like to recognize our program sponsors, who provided critical overall financial support for NESTA's activities in San Antonio. Program sponsors included the American Geophysical Union (at the Diamond Level), and Howard Hughes Medical Institute and the American Meteorological Society (at the Platinum Level).

On Thursday, the **NESTA Board** met to go over accomplishments of the past year, to work on plans for the coming year, and to vote on several issues, including our upcoming dues increase.

Early Friday morning, we held our **NESTA VIP Breakfast**, at which we honor those who have given so much to NESTA over the past year – including volunteers as well as organizations supporting our efforts. A list of those honored by NESTA appears in the pages of this issue. Thanks to everyone who has supported NESTA over the past year. Without your efforts and support, NESTA could not have the impact it does for so many teachers across the country!

Our **Share-a-Thons** on Friday and Saturday were a great success! Thanks so much to Michelle Harris, our Share-a-Thon Coordinator, for all her hard work at organizing these events, making arrangements for acknowledgement/thank-you letters to presenters, and coordinating assembly of activity sets for all the presenters. Thanks also to all the volunteers that helped out in the Share-a-Thons. And a huge thanks to our Share-a-Thon sponsors: University Space Research Association, Earth Science Information Partners, Integrated Research Institutions in Seismology, Northrup-Grumman, Ocean Leadership and Ball Aerospace, who provided critical financial support for these events.

Continuing our approach of the past several years, we also offered five **topical workshops** to teachers – all workshops were well attended, with 30 to 50 participants in each! Workshop topics included climate change, geology, Earth system science, planetary science and astronomy.

In addition to our workshops, NESTA hosted the **AGU Lecture** at NSTA on Friday afternoon. The lecture was presented by Prof. Andrew Dessler, of Texas A&M University, on “*The Climate Science Debate: What Does the Science Tell Us and Why People on Both Sides Are So Angry About It*”. The lecture was introduced by our President Elect, Dr. Michael Passow, and was attended by over 100 teachers.

On Friday evening, NESTA hosted the **Friends of Earth Science Reception**. We were delighted to have well over 130 attendees at this enjoyable event where we honored Nathan Shotwell, the

NESTA Contacts

REGIONAL DIRECTORS

Central Region - IL, IA, MN, MO, WI
Chad Heinzl
chad.heinzl@uni.edu

East Central Region - IN, KY, MI, OH
Jay Sinclair
sinclair.jay@sbcglobal.net

Eastern Region - DE, NJ, PA
Peter Dorofy
pdq72@optimum.net

Far Western and Hawaii Region - CA, GU, HI, NV
Wendy Van Norden
wannorden@hw.com

Mid-Atlantic Region - DC, MD, VA, WV
Michelle Harris
michelle_harris@apsva.us

New England Region - CT, ME, MA, NH, RI, VT
Lisa Sarah Alter
lalter@snet.net

New York Region - NY
Gilles Reimer
greimer@hvc.rr.com

North Central Region - MT, NE, ND, SD, WY
Cassie Soeffing
cassie_soeffing@strategies.org

Northwest Region - AK, ID, OR, WA & British Columbia
VACANT

South Central Region - AR, KS, LA, OK, TX
Wendy DeMers
2ydnw2@gmail.com

Southeastern Region - AL, FL, GA, MS, NC, PR, SC, TN
Dave Rodriguez
cdrodriguez@mac.com

Southwest Region - AZ, CO, NM, UT
Pamela Whiffen
pwpwr@aol.com

Appointed Directors

Tom Ervin – tomervin@mchsi.com

Ron Fabich –
rfabich@zoominternet.net

Parker Pennington IV –
p.o.pennington@gmail.com

Rick Jones –
rmjones7@hawaii.edu

Joe Monaco – monacoj@aol.com

John Moore – mr.moore.john@gmail.com

NESTA Coordinators

Affiliates Coordinator

Ron Fabich
rnfabich@gmail.com

Conference Logistics Coordinators

Kim Warschaw
kschlusssel@cox.net

Michelle Harris
michelle_harris@apsva.us

Membership Contact

Marlene DiMarco
Phone: 702-982-8349
Marlene.DiMarco@gmail.com

Merchandise Coordinator

Howard Dimmick
dimmick@esteacher.org

Procedures Manual Coordinator

Parker Pennington IV
p.o.pennington@gmail.com

Rock Raffle Coordinators

Parker Pennington IV
p.o.pennington@gmail.com

Kimberly Warschaw
kschlusssel@cox.net

Share-a-thon Coordinator

Michelle Harris
michelle_harris@apsva.us

Volunteer Coordinator

Joe Monaco
MonacoJ@aol.com

Webpage Coordinator

Jack Hentz
hentz@aaps.k12.mi.us

E-News Editor

Richard Jones
rmjones7@hawaii.edu

recipient of the **American Geosciences Institute Edward G. Roy Award for Excellence in K-8 Earth Science Education**. HHMI's BioInteractive team shared several new, free resources for the earth science classroom, including the short film, "The Day the Mesozoic Died," the "Changing Planet: Past, Present, Future" program featuring Andy Knoll, Naomi Oreskes, and Dan Schrag (free on DVD and as VOD from BioInteractive.org), and the EarthViewer app for iPad. We were happy to offer our second silent auction (thanks to Michelle Harris and Kimberly Warschaw, who organized the auction, as well as those that donated resources to the auction!), at which we were able to raise over \$900 for NESTA! Thanks so much to our sponsors, including HHMI, Carolina Biological, and the American Geosciences Institute, who together provided support for the reception, which is the most costly event in NESTA's schedule of events at NSTA!

On Saturday, our lunchtime lecture given by Dr. Mark Nielsen of HHMI focused on *If These Rocks Could Talk: Earth's Climate in the Deep Past*. Last year we decided that including a ticketed luncheon was making it difficult for teachers to attend (due to the cost of the luncheons) so we instead decided to refer to it as a "Lunchtime Lecture", and encourage people to bring their lunches. We were delighted that this approach appeared to work, and over 50 people were able to enjoy the lecture and find out about the excellent resources offered by HHMI.

Our Rock and Mineral Raffle, on Saturday afternoon, was as usual a great success, with lots of happy winners! We had well over 50 specimens available, as well as many give-aways donated by generous individuals. The raffle raised over \$1500 for NESTA, and was attended by over 100 participants. Thanks to Parker Pennington and Kimberly Warschaw for their efforts in so successfully organizing the Rock and Mineral Raffle, as well as to all the generous donations from individuals and organizations.

Our events in San Antonio closed on Saturday with the **Annual NESTA Membership Meeting**. The hardy 20+ attendees heard about NESTA plans for the coming year, and shared their insights about what we should do in the coming year.

In addition to our events at the conference, NESTA also had a booth in the **Exhibit Hall**, which was well visited, and was responsible for generating an additional ~ 40 NESTA memberships (in addition to the ~ 40 people who joined in our main presentation room), this in addition to merchandise sales. A huge "Thank You" to NESTA's Administrator, Marlene DiMarco, who put up and took down the booth, and also was chiefly responsible for shipping back resources from the conference. Marlene was the mainstay of the staff at the booth (doing an EXCELLENT job), and we are thankful that several individuals also volunteered to help out in the booth, including John Herrold, Gail Gant, Tina Harris, and Denise Smith.

As you can see, putting the NESTA program on at the NSTA National Conference is a major undertaking, requiring the support of many individuals and organizations. Thanks to everyone that made this possible, and we look forward to another successful conference next Spring!

Best Regards,
Dr. Roberta Johnson
Executive Director, NESTA

Check Out HHMI-BioInteractive's excellent resources for teachers at the following links:

- EarthViewer <http://www.hhmi.org/biointeractive/earthviewer/index.html>
- Changing Planet lecture series http://www.hhmi.org/biointeractive/earth_history/
- Paleoclimate, geologic history of O₂, and deep history of life on earth interactive features <http://www.hhmi.org/biointeractive/click/index.html>
- The Day the Mesozoic Died short film <http://www.hhmi.org/biointeractive/shortfilms/>

EDITOR'S CORNER

Welcome to the third special issue of *The Earth Scientist* sponsored by the Penn State TESSE team! Transforming Earth System Science Education (TESSE) was funded by the National Science Foundation (NSF GEOTeach Award #0631377) with The Pennsylvania State University as one of four institutions involved in intensive and sustained teacher professional development, targeting the teaching and learning of Earth system science.

In the summers of 2011 and 2012, with funding from a Targeted Math Science Partnership (MSP) grant (NSF Award #DUE-0962792), we welcomed middle and high school Earth and Space science teachers from partner school districts in Pennsylvania for summer workshops in plate tectonics, solar system astronomy, energy production, and climate change. Our Penn State Earth and Space Science Partnership (ESSP) presented each discipline-based workshop with a common pedagogical approach including content storyline, formative assessment, and claims-evidence-reasoning.

In addition to our summer workshop offerings, we encourage teachers to pursue other avenues of professional development. Certainly, publishing curricular innovations in *The Earth Scientist* not only empowers teachers but helps to elevate the teaching profession and provide a voice for advocacy in the discipline (see Guertin and Furman, 2013). We have worked hard alongside teachers to establish and sustain the Pennsylvania Earth Science Teachers Association (PAESTA, <http://www.paesta.org/>), the Pennsylvania chapter of NESTA. PAESTA offers the opportunity for leadership and engagement for the teaching community online and at our annual conference.

The articles featured in this issue reflect the enthusiasm, hard work and success of the teachers and Penn State project leaders in developing quality classroom activities and professional development opportunities available through PAESTA. We hope you will enjoy these articles, incorporate some of these innovative ideas and resources into your own classroom, and join up in supporting PAESTA and NESTA!

Penn State TESSE and ESSP Project Leaders and Guest Writers of this *Editor's Corner* –

Tanya Furman, Laura Guertin

Tom Ervin
TES Editor

Citation

Guertin, L., & T. Furman (2013). Mentoring middle school and high school Earth science teachers to publish. *In the Trenches*, 3(1): 4-5.

HELP WANTED!

NESTA needs you to help run our events at the 2013 Fall NSTA Area Conferences in Portland, Charlotte and Denver. We need volunteers to help with our Share-a-thons and Rock Raffles. If you feel that you can help, contact Joe Monaco, NESTA Volunteer Coordinator: monacoj@aol.com

The Earth Scientist

EDITOR

Tom Ervin

PUBLICATIONS COMMITTEE

Linda Knight, Chair
Tom Ervin, TES Editor
Parker Pennington IV
Howard Dimmick
Ardis Herrold
Missy Holzer
Richard Jones

CONTRIBUTING AUTHORS

Lauren Beal, Meredith Hill Bembenic, Bryan Brightbill, Greg Collins, Abigail Dufoe, Alice Flarend, Tanya Furman, Laura Guertin, Jennifer Hoffman, Kelly Hunter, Theresa Lewis-King, Peter Licon, Scott McDonald, Christopher Palma, Megan Pickard, Eliza Richardson, Seyed Mehdi Kamali Shahri, Heather Spotts

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To become a member of NESTA visit www.nestanet.org.

To get more information about NESTA or advertising in our publications, or to get copies of back issues, contact the NESTA Office at 720-328-5351 or marlene.dimarco@gmail.com

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NESTA Membership Dues Structure

Basic Membership (US and International) –

includes access to the online version of *The Earth Scientist*, E-News, special e-mailings, access to member-only sections of the website, and full voting privileges.

- One year – \$30
- Two years – \$60
- Three years – \$90

Membership with Print Supplement (US) –

includes both printed and access to online versions of *The Earth Scientist*, E-News, special e-mailings, access to member-only sections of the website, and full voting privileges.

- One year – \$50
- Two years – \$95
- Three years – \$140

Membership with Print Supplement (Mexico and Canada) –

same benefits as NESTA Membership with Print Supplement.

- One year – \$60
- Two years – \$115
- Three years – \$170

Domestic Library Rate –

includes print copies of *The Earth Scientist* only, and does not include NESTA membership

- One year – \$70

Windows to the Universe Educator Membership –

provides access to special capabilities and services on NESTA's premier Earth and Space Science Education website available at <http://windows2universe.org>, available for only \$10/year for NESTA members (50% off the non-NESTA rate). Join today!

NESTA Awards Presented in San Antonio

By Tom Ervin, Dr. Richard Jones, and Parker O. Pennington, IV

4/12/2013 – The National Earth Science Teachers Association (NESTA) is a volunteer based organization. We depend upon the efforts of our volunteers, and the support of our sponsors to make possible the services we provide. Each year, at the NSTA National Conference on Science Education, NESTA makes a special effort to recognize those who give of themselves for the betterment of NESTA. This year, in San Antonio, the following people and organizations were so recognized:

Certificates of Appreciation were presented to the following individuals or organizations:

- American Geophysical Union (AGU) for their continuing sponsorship of NESTA's ads in the NSTA Program and NSTA Reports at the Diamond Sponsorship Level, their support for the AGU Lecture, their support for and collaboration on the AGU-NESTA GIFT Workshops at the Fall AGU Conference, and for the Union's Founding Partnership with Windows to the Universe
- Geoff Camphire, American Geosciences Institute (AGI) for sponsorship of NESTA's Friends of Earth Science Reception at the Silver Sponsorship Level, providing 50, 2012 Earth Science Week Packets to NESTA members and Earth Science week posters for the Fall issue of *The Earth Scientist*, and its support as a Founding Partner with Windows to the Universe
- American Meteorological Society (AMS) for sponsorship of NESTA's events at the 2013 NSTA National Conference in San Antonio at the Platinum Sponsorship Level
- Ball Aerospace Technologies for sponsorship of NESTA's events at the 2013 NSTA National Conference in San Antonio at the Silver Sponsorship Level
- Carolina Biological for sponsorship of NESTA's Friends of Earth Science Reception at the Silver Sponsorship Level and their support in the form of material donations to the NESTA Rock and Mineral Raffle and Silent Auction
- Chandra X-Ray Observatory for their sponsorship of the Spring 2012 issue of *The Earth Scientist* and for contributions of inserts for this issue
- Learn More About Climate, Climate and Energy Educators for their continued loyal advertising in *The Earth Scientist* in 2012
- Deep Earth Academy for their support of NESTA's Share-a-Thon events at the 2013 NSTA San Antonio Conference
- Dr. Andrew Dressler of Texas A&M University for presenting the AGU Lecture, "The Climate Science Debate: What Does the Science Tell Us and Why People on Both Sides Are So Angry About It" at the 2013 NSTA Conference in San Antonio
- Earth Science Information Partners (ESIP) for their financial support of NESTA's Share-a-Thons at the 2013 NSTA San Antonio Conference
- Earth & Space Models, GeoBlox for their continued loyal advertising in *The Earth Scientist* in 2012

- Howard Hughes Medical Institute (HHMI) for sponsorship of NESTA's events at the 2013 NSTA National Conference at the Platinum Sponsorship Level
- John Taber, Incorporated Research Institutions for Seismology (I.R.I.S.) for their financial support of NESTA's Share-a-Thons at the 2013 NSTA San Antonio Conference
- What If? Scientific, Leave Only Bubbles for their continued loyal advertising in The Earth Scientist in 2012
- National Oceanic and Atmospheric Administration (NOAA) for their financial support of NESTA's Fall 2012 – Spring 2013 Professional Development Program
- Dr. Mark Nielson Science Education Fellow of the Howard Hughes Medical Institute for presenting the NESTA Luncheon Lecture, "If These Rocks Could Talk: Earth's Climate in the Deep Past" at the 2013 NSTA Conference in San Antonio
- Peg Steffen, NOAA of NOAA, for poster contributions to the Summer and Winter 2012 issues of The Earth Scientist
- Northrup Grumman for their support of NESTA's Earth System Science Share-a-Thon at the 2013 NSTA Conference in San Antonio
- The Owners Manual, Passport to Knowledge Earth – T.O.M. for their continued loyal advertising in The Earth Scientist in 2012
- The Edge Of Kauai (T.E.O.K.) Tours for their continued loyal advertising in The Earth Scientist in 2012
- Simulation Curriculum, The Layered Earth for their continued loyal advertising in The Earth Scientist in 2012
- Universities Space Research Association (URSA) for their financial support of NESTA's Share-a-Thons at the Silver Sponsorship Level for the 2013 NSTA San Antonio Conference

John Taber receiving IRIS's Certificate of Appreciation from NESTA President Missy Holzer (left) and Executive Director Dr. Roberta Johnson (right).



Geoff Camphire receiving AGI's Certificate of Appreciation.

Certificates of Service were presented to the following NESTA members who, during the past year, contributed to the well being of NESTA:

- Ann Brown For service as Receiver at the NSTA National Conference in San Antonio, 2013
- Eddie Cohen for service as the North Central Regional Director on the Board of Directors, 2012-201
- Tom Ervin for help presenting NESTA's events at the NSTA National Conference in San Antonio and for his continued service as TES Editor
- Michelle Harris for organizing NESTA's Share-a-Thons in Fall 2012 – Spring 2013 and for help presenting NESTA's workshops and events at the Atlanta NSTA Regional Conference in 2012 and National conference in San Antonio in Spring 2013
- Chad Heinzl for service as the Central Regional Director on the Board of Directors, 2011-2013
- Ardis Herrold for help presenting NESTA's workshops and events at the Atlanta and Louisville NSTA Regional Conferences in 2012 and the Spring 2013 Conference in San Antonio

- Dr. Roberta Johnson for coordinating NESTA's programs at the NSTA Fall 2012 Regional and Spring 2013 National Conference, organizing and leading workshops at these conferences, and for providing major financial support of all of NESTA's programs through the Windows to the Universe project
- Dr. Richard Jones for help presenting NESTA's workshops and events at the Phoenix NSTA Regional Conference in 2012 and for his continued service as ENews Editor
- Kurtis Koll for service as the South Central Regional Director on the Board of Directors, 2011-2013
- Randal Mandock for service as Receiver at the NSTA Area Conference in Atlanta, 2012
- Dr. Michael Passow for help presenting NESTA's workshops and events at the Louisville NSTA Regional Conference in 2012 and the National Conference in San Antonio in Spring 2013
- Parker Pennington, IV for help presenting NESTA's workshops and events at the Atlanta NSTA Regional Conference in 2012 and the Spring 2013 Conference in San Antonio
- Gary Potter for service as Receiver, and at our events at the NSTA Area Conference in Louisville, 2012
- Gilles Reimer for service as the New York Regional Director on the Board of Directors, 2011-2013 and for representing NESTA at the Fall 2012 STANYS Conference
- Wendy Van Norden (2) for help presenting NESTA's workshops and events at the Phoenix NSTA Regional Conference in 2012 and the Spring 2013 Conference in San Antonio for service as the Far West Regional Director on the Board of Directors, 2011-2013
- Pam Wiffin (2) for assistance at the NSTA Area Conference in Phoenix, 2012
- For service as the Southwest Regional Director on the Board of Directors, 2011-2013

The **Thomas B. Ervin Distinguished Service Award** is presented to officers and volunteers who provide dedicated service to NESTA. In San Antonio, this Recognition was presented to the following NESTA members.

- Ronald Fabich for Services Rendered in the Promotion of Earth Science Education, and Service to NESTA
- Ardis Herrold for Services Rendered in the Promotion of Earth Science Education, and Service to NESTA
- Missy Holzer for Services Rendered in the Promotion of Earth Science Education, and Service to NESTA



Ardis Herrold receiving her Thomas B. Ervin-DSA Certificate.



Missy Holzer receiving her DSA Certificate.



Parker Pennington receiving his DSA Certificate.



Kim Warschaw receiving her DSA Certificate.

- Dr. Richard Jones for Services Rendered in the Promotion of Earth Science Education, and Service to NESTA
- Joe Monaco for Services Rendered in the Promotion of Earth Science Education, and Service to NESTA
- Parker Pennington, IV for Services Rendered in the Promotion of Earth Science Education, and Service to NESTA
- Kimberly Warschaw for Services Rendered in the Promotion of Earth Science Education, and Service to NESTA

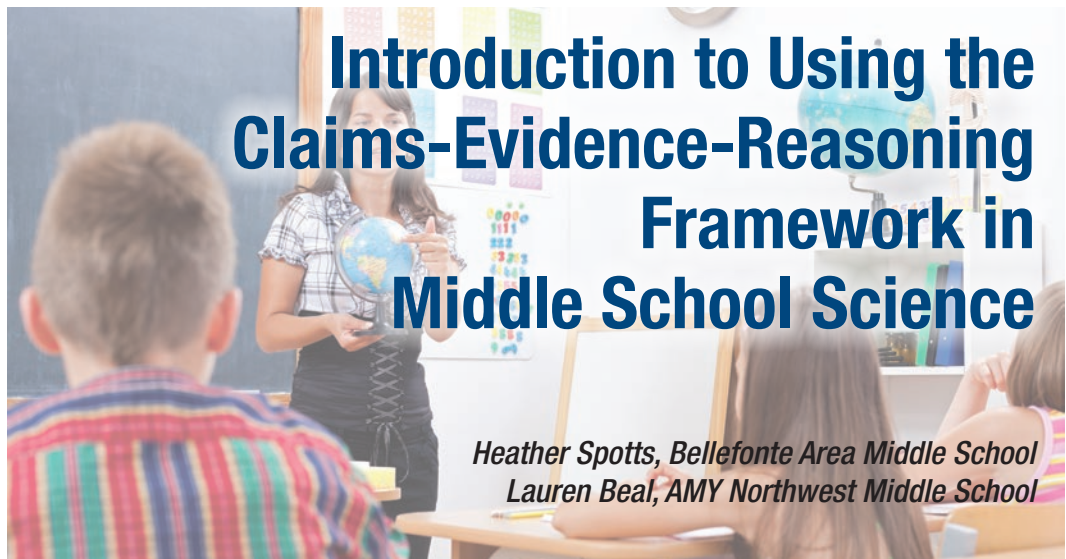
Fellows of the Association must have been members for at least five years and shall have contributed substantially and with excellence to Earth Science education and to NESTA itself. In San Antonio, this Recognition was presented to the following NESTA members.

- Lisa Alter In Recognition of Past Achievements and Contributions to the Goals of the Association
- Carl Katsu In Recognition of Past Achievements and Contributions to the Goals of the Association

The Jan Woerner and Harold B. Stonehouse Award for Lifetime Achievement

This Award, named in honor of NESTA's first President, Janet J. Woerner, and its first Executive Advisor, Harold B. Stonehouse, is given at the discretion of the NESTA Executive Committee in recognition of an individual or organization's lifetime effort in promoting Earth Science Education in keeping with the goals of NESTA. This award includes a plaque and a lifetime NESTA membership. This Award is NESTA's highest form of recognition. In our entire history this award has only been presented to 7 individuals, and one organization, the Michigan Earth Science Teachers Association (MESTA). This year, in San Antonio, it was presented to two individuals. The extent of their importance to NESTA and their impact on Earth Science Education can be seen in the wording of their respective plaques:

- Sharon Stroud In Recognition Of Her Many Years Of Dedication And Service To NESTA, In Particular, Her Inspired Genius During NESTA's Early Years When As President, She Originated The Share-a-thons, Rock Raffles, And President's Reception.
- K Rod Cranson In Recognition Of His Many Years Of Dedication And Service To Earth Science Education, In Particular, His 1967 Founding Of The Michigan Earth Science Teachers Association, Which Became The Template For The 1983 Founding Of NESTA.



Introduction to Using the Claims-Evidence-Reasoning Framework in Middle School Science

*Heather Spotts, Bellefonte Area Middle School
Lauren Beal, AMY Northwest Middle School*

Abstract

This article reports on the Claims-Evidence-Reasoning (CER) framework for scientific explanation in two different middle school classroom environments. Initial implementation of this methodology brought immediate successes and challenges in both sixth and eighth grade classrooms. No differential struggles were observed across the grade levels explored here, as both groups faced the same challenges with adopting this new method for doing and describing science. It is expected that with the introduction of the CER framework at the lower grades this picture will change, as students who employ the framework grow rapidly in their abilities and could be expected to show greater facility over time. Effective strategies for improving quality of student explanations in the science classroom include structured peer review and exchanges of ideas among students. Incorporating the CER framework resulted in substantial observed improvements in student engagement, argumentation and use of evidence in class discussions.

Introduction

The *National Science Education Standards* (National Research Council, 1996) and *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993, 2009) advocate the importance of scientific explanations in K-12 classrooms. The process of engaging students in scientific explanation has been shown to help them to better understand science concepts, to reason logically, to use evidence to support claims, and to both consider and critique alternative explanations as part of understanding the nature of science (McNeill and Krajcik 2012). This approach is supported in the writing strand of the Common Core State Standards Initiative English Language Arts which highlights that students should be able to write scientific arguments based upon claims, evidence, and reasoning (Common Core State Standard, 2010).

Constructing scientific explanations can be challenging for students and requires multiple guided opportunities to practice. The Claims-Evidence-Reasoning (CER) framework presents an explicit method of teaching students how to write and use scientific explanations in the classroom (McNeill and Krajcik, 2012). It mirrors the Claim-Data-Warrant model for analyzing arguments and open-ended scenarios (Toulmin, 1958) employed in English and Social Studies classrooms. This more recent application to the science classroom reflects an increasing desire to incorporate inquiry-based and problem-based learning strategies that require students to formulate interpretations rather than simply generating data and recording them on worksheets while trying to answer prescribed questions.

The framework's three components are: (1) the Claim, a statement that answers a scientific question; (2) the Evidence, a summary of the quantitative and qualitative data that support the claim; and (3) the Reasoning, a logical discussion of the underlying scientific concept or principle that connects the claim and the evidence. The CER framework allows students to move effectively from analyzing collected data to formulating a conclusion because emphasis is placed on making sense of the data and delving deeply into the scientific concepts that explain what is happening in the activity. Students are encouraged to think critically and challenge each other's ideas in the pursuit of scientific understanding.

Initial Implementation

The authors were introduced to the CER model during summer workshops sponsored by the Earth Science Space Partnership (ESSP) through the Pennsylvania State University. ESSP is a collaborative project among Penn State scientists and science educators, along with practicing teachers from seven school districts across Pennsylvania. During the week-long workshops, the teachers received instruction in CER and practiced using the framework. In the subsequent school year, they began adapting existing science activities to this new model. This article reports on the successes and challenges that were experienced, and outlines strategies that were found helpful for the students and the authors.

During the first weeks of the school year, two classrooms of middle school students (reported on in this article) received direction instruction in the framework and on its importance. In the urban eighth grade classroom, students received initial direct instruction on the entire framework using non-science examples, and followed this instruction with several opportunities to use the entire framework during subsequent inquiry lab investigations. In the rural sixth grade classroom, the students were initially introduced to the entire framework, but then focused on framework components individually through science inquiry labs.

In both classrooms, the scientific questions were provided to the students. Students then conducted the investigations that led to development of claims and evidence. Working in small groups, the students made claims, which they shared with the class while the teacher recorded a class consensus. Any discrepancies among claims led to discussion of supporting evidence. This guided discussion allowed the teachers to reinforce the components of the framework; many students struggled to understand the meaning of "evidence". As an example, in an activity that involved measuring angles of light incidence and reflection from shining a laser pointer on a reflective surface, one sixth grader stated simply "the data was our evidence". The teacher first guided the student to both realize and articulate the observation that the angles measured were the same in both cases. She then helped the student build on that observation by verbalizing that the numbers in the "Angle of Incidence" column were the same as the numbers in the "Angle of Reflection" column. Through this process, the student was then able to describe and codify her understanding that the angle of incidence equals the angle of reflection. The need for this type of conversation reinforced the chosen approach of providing the questions, for often students can easily become overwhelmed or distracted by trying the CER approach without ample scaffolding.

Figure 1. Sample work from a 6th grade student using Claims, Evidence and Reasoning (CER) one month after the first classroom introduction to this approach.

Photo by Heather Spotts.

Q: What happens to a beam of light when it hits a reflective surface?

Angle of incidence	Angle of reflection
30°	
45°	
75°	
On your own	

Diagram: A laser pointer is mounted on a protractor. A mirror is placed on a surface. The angle of incidence is 30°, and the angle of reflection is 30°. Labels include 'laser holder', 'protractor', and 'mirror'.

Evidence:

- 30° When you shoot the laser at 30° it bounces back at 30° on the opposite side.
- 45° When you shoot the laser at 45° it bounces back at 45° on the opposite side.
- 75° When you shoot the laser at 75° it reflects at 75° on the opposite side.
- 90° When you shoot the laser at 90° it reflects at 90° on the opposite side.

Claim (C): The laser reflects off at an equal angle that it hits.

Evidence (E): The numbers in the left column were the same as the #s in the right column.

Reasoning (R): The law of reflection.



Figure 2. Throughout the unit, students posed over 700 thought provoking questions on this class “Parking Lot”. The shared efforts of the 6th grade students, the teacher, Penn State University graduate students and faculty members helped answer all of these questions.

Photo by Heather Spotts.

Although appropriate questions were provided to the students, the authors noticed an increase in student inquisitiveness; students quickly showed growth in their ability to develop their own questions. In the sixth grade classroom, in just one period of class, students developed a series of questions that addressed nearly all of the concepts that the teacher had already planned for the entire unit. A posted inquiry chart recording student-designed questions for future investigations was quickly filled. In the instance of the sixth grade classroom, a GoogleDoc was generated so that the faculty and graduate students of Penn State could correspond with the teacher to help answer the more difficult student questions. The authors used these student-generated questions to guide subsequent investigations.

Initial Successes and Challenges

The authors noticed students’ quick grasp of the concept of a “claim”. The majority of students were soon able to write their own claims, or to respond with a clear statement in answer to a specific scientific question. The authors also witnessed an improvement in students’ choice of evidence as they began to recognize and verbalize the power of multiple sources of evidence in their explanations. When prompted for evidence, a small number of sixth

and eighth grade students initially did struggle with the need to provide enough *specific evidence* to support their claims. Some students, like the one quoted earlier, initially recorded “the data chart” or “the experiment.” Once guided through the process, however, their ability to recognize and cite appropriate evidence improved rapidly. The majority of students in both the sixth and eighth grade classrooms struggled with the “reasoning” component of the framework. In many cases, students simply wrote a concluding sentence to end their explanation rather than constructing a paragraph based on reasoning. This aspect of the framework is the most challenging as well as the most fundamental to the practice of science, and the authors developed the following strategies to help students improve their ability to reason and evaluate their evidence critically.

Strategies to Improve Quality of Student Scientific Explanations

After the initial introduction and first uses of CER in their classrooms, the authors engaged in several guided activities aimed at improving student use of the framework. These strategies are outlined below, with suggestions given in regard to timeline, process, result and potential challenges of each approach. In each of these activities, the teacher acted as the facilitator, using appropriate opportunities to re-teach and reinforce specific components while primarily guiding student discussion around use of the framework.

Peer Review

A peer review activity was designed to model constructive feedback among students and to challenge them to provide specific feedback that went beyond “good job” or “work on your claim.” In this peer review activity, the teacher reviewed the CER framework as a whole class lesson, and after completing a lab, guided students through two student group examples of CER. The teacher chose to focus specifically on the reasoning component, as this was the main area of weakness across the grade. Students then worked in collaborative groups to analyze one or more CER write-ups and

presented their feedback to the whole class. After engaging in a class discussion about the suggested feedback, students returned to their original lab groups and revised their own initial CER responses.

While the peer review activity might not be done every time, there is value in using this instructional strategy after all the students have written their first CER report, and then requiring submission of a revised document based on feedback. In this situation, the authors noticed a significant improvement in the revised CER reports, especially in the area of students' reasoning. This strategy proved to be especially useful when targeting a specific aspect of the written report.

Gallery Walk

A gallery walk activity provided students with the opportunity to see a variety of student responses and again practice constructive feedback. In this gallery walk activity, the teacher started the lesson by reviewing the CER framework. Students worked in pairs to write a CER report using data from a recent lab. The student responses were posted on chart paper and displayed around the room. The teacher modeled procedures and constructive feedback. With their partner, students took a "gallery walk" around the room and used sticky notes to provide feedback for the posted CER reports. The lesson concluded with a whole class discussion and a self-reflection about the activity.

After facilitating several Gallery Walk activities, the authors witnessed continued improvement in students' ability to evaluate peer responses and to provide constructive feedback. Students' self-reflections also revealed the additional benefit of seeing their work in comparison to others. One of the eighth graders wrote, "I thought ours was good until I saw everybody else's. Now I see what everybody means when they said we didn't give enough evidence and our claim wasn't clear. We should have given more than two sources of evidence."

Board Meeting/Class Meeting

Similar to a Gallery Walk, the Board Meeting is a class meeting activity that allows students the opportunity to engage in a whole class discussion about student CER responses. In this activity, each group wrote their CER report on chart paper. The groups displayed and shared their work with the rest of the class, looking for similarities, differences and errors. The teacher modeled appropriate guidelines for discussion, such as "I politely disagree because..." Students participated in critiquing their peers' CER reports by questioning aspects of claims or evidence. The authors found the Board Meeting activity to be extremely effective in helping students identify the most appropriate CER components. The students quickly revealed an increased ability to notice errors, question their peers and engage in positive argumentation. Regardless of grade, students were engaged participants. The sixth grade students, however, required the teacher's encouragement to establish a sense of ownership in the process, instead of immediately looking to the teacher for what was deemed as the correct answer. This was fostered further, by continually asking the students for their opinion, instead of quickly providing judgment.

Cross-curricular Comparisons

Throughout the first months of school, teachers and students engaged in conversations comparing and contrasting the construction of explanations in science to written responses in language arts, social studies and math. Upon introduction of the framework, the eighth grade students immediately drew parallels between the CER framework and the writing outline used in the language



Figure 3. Students participating in a Gallery Walk activity.

Photo by Lauren Beal.

About the Authors

Lauren Beal is an eighth grade Science teacher at AMY Northwest Middle School in Philadelphia, PA. She received her Masters degree in Integrated Science Education from the University of Pennsylvania in spring 2008. Lauren can be reached at lgbeal@philasd.org.

Heather Spotts is a sixth grade Science teacher at Bellefonte Area Middle School, Bellefonte, PA. In December 2013, she will complete her master's degree in Curriculum and Instruction with an emphasis in Language and Literacy Education at The Pennsylvania State University, University Park, PA. Heather can be reached at heatherspotts@gmail.com

arts classrooms. This observation led to a discussion of the similarities and differences between providing data as evidence in science and giving supporting details in language arts. This discussion also helped to spotlight one potential difficulty the students had constructing their reasoning paragraphs. In language arts, students write a single concluding sentence, whereas with the CER framework the reasoning component demands that students use their understanding of the underlying science principles to connect their claim and evidence.

Results of CER Use in the Classroom

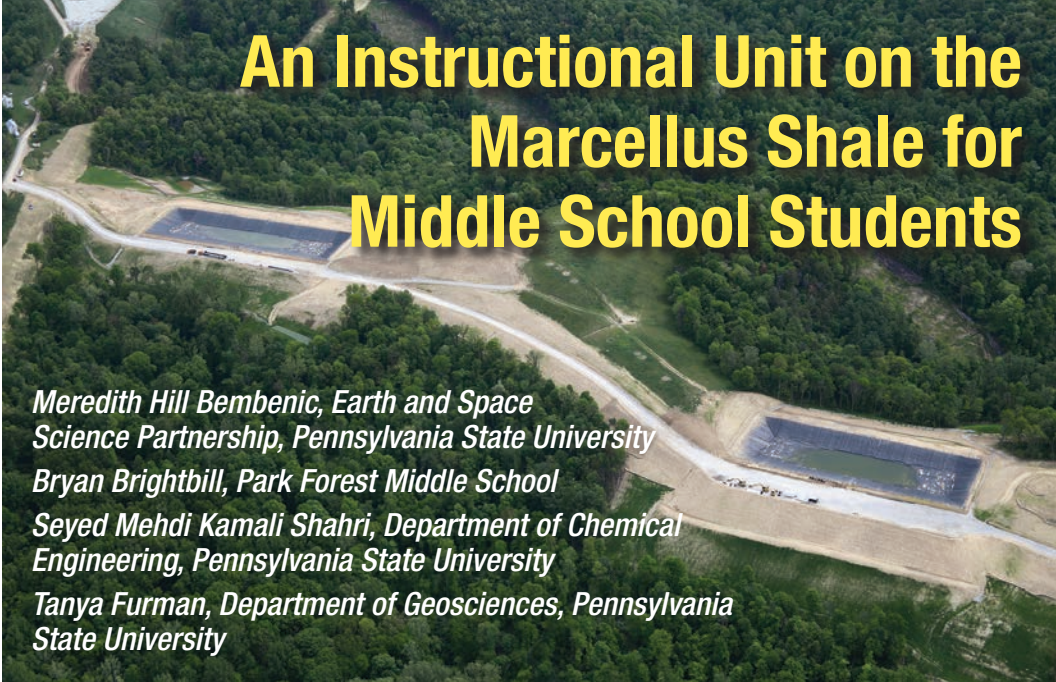
After implementing CER during the first months of the school year, the authors found similar results in both the sixth and eighth grade classrooms. In the sixth grade classroom, a heightened level of awareness was evident from the number of recorded visits to the class website. This year, on the class website, the author posted all lab CER reports. In just one month, the site recorded more than 650 views, compared to fewer than 50 in the previous year. Parents also provided positive feedback about the framework during student conferences; many remarked they liked having the posted CER documents as a technique for them to see what students were doing in class, and as a study tool for their child.

The authors observed an increased level of student inquisitiveness and a deeper understanding of the content. Both also witnessed a heightened demand for evidence from peers and discourse that reflected more highly structured arguments. In both classrooms, "What's your evidence?" has become a common question asked by students to their own classmates. Student work samples in both grades from September through January show a steady improvement in student claims, evidence and reasoning.

The authors' report of the introduction of CER and subsequent challenges, successes and activities were based on the first five months of the 2012-2013 school year. As stated earlier, the authors noticed a significant increase in student engagement, focus on evidence, and heightened levels of argumentation. As this school year progresses, the authors will continue to make CER a focal point in their science classrooms and continue to document their challenges, successes and follow-up lessons. While it is noted that the authors' claims of success are observational in nature, during in the 2013-2014 academic year, the authors intend to measure student engagement through a quantitative analysis of pre and post-assessments. In a push for adoption of the framework in their own schools, the authors will continue to share with their colleagues, their very positive CER experiences.

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An Instructional Unit on the Marcellus Shale for Middle School Students

Meredith Hill Bembenic, Earth and Space Science Partnership, Pennsylvania State University
Bryan Brightbill, Park Forest Middle School
Seyed Mehdi Kamali Shahri, Department of Chemical Engineering, Pennsylvania State University
Tanya Furman, Department of Geosciences, Pennsylvania State University

Abstract

Central Pennsylvania is an area rich in natural energy resources with a complex geologic history. Classroom investigations often focus on how the modern regional topography developed following formation of the Appalachian Mountains. The last ten years have seen tremendous interest in utilizing natural gas, especially from the Marcellus Shale, as an alternative to coal and petroleum for providing electricity and transportation fuel. This article presents a Marcellus Shale instructional unit spanning five instructional days as part of a cohesive Earth Science curriculum for middle school students in central Pennsylvania. Students investigate relevant geologic, environmental, and social issues for this particular natural gas formation along with energy exploration in general. The Marcellus Shale instructional unit consists of readings, in-class instruction and activities that help students to connect this content with preceding and subsequent learning.

Background/Introduction

Widespread interest in the Marcellus Shale provides the opportunity to introduce several new Earth system science concepts at the middle school level including: 1) clays as important sedimentary minerals, 2) hydrocarbon formation stemming from entrapment of organic material during sediment deposition, and 3) shale as an important sedimentary rock that has been deposited on passive margins (i.e., a transition between continental and oceanic crust that is not associated with a plate boundary). Students will also recognize that Earth system science extends below the surface to landscapes that cannot be seen. The unit is intended to connect with and transition to other lessons in the broader context of middle school Earth Science (e.g., rocks and minerals, geology and geography, global climate change), but can also be used as a stand-alone instructional unit.

This unit was developed collaboratively by a graduate student and a postdoctoral researcher in the energy field (Kemali and Bembenic) in consultation with a middle school science teacher (Brightbill). Brightbill collaborated with other English and science teachers at his local school to design appropriate assessments based on the unit material that encourage integrative thinking across disciplines.

Unit Components and Implementation

This article presents a five-day instructional unit organized to engage students in the scientific foundation of a topic that has widespread and far-reaching political and economic significance in many parts of the nation. The unit is organized around multiple instructional components:

Day 1: Introductory slide-show evoking prior knowledge, followed by a hands-on activity to investigate the energy resource properties of local sedimentary rocks

Day 2: Simulated hydrocarbon prospecting activity

Day 3: Exploration of an online Marcellus information resource

Day 4: Class discussion of benefits and challenges in energy exploration

Day 5: Writing a position letter regarding hydrofracturing to extract natural gas

The variety of activities allows students to become involved in constructing their own knowledge regarding our hydrocarbon-based natural resources. Some of the components lend themselves to stand-alone use, while others are best contextualized within a longer unit.

Day 1: Geologic Formation of Sedimentary Rocks and Minerals

Through prior learning and in-class discussion, students are reminded how shale forms, including the time scale of its formation. This step was carried out effectively by connecting this lesson to an immediately preceding unit on the geomorphology of central Pennsylvania (Ellis et al., 2009). Through use of a slide-show based discussion, the location of the Marcellus Shale resource play is introduced to the students so they can begin to identify the geological features and rock types associated with this formation. A resource play, often abbreviated as play, is a term used to describe large, known sources of gas trapped beneath the earth's surface (Encana, 2013). A typical cross sectional map of central Pennsylvania geology was shown to the students with the location of the Marcellus Shale indicated. In addition to observing and describing important sedimentary rocks, students also made their own sedimentary rock using Epsom salt, water, gravel and sand (Rogers Group Inc., 2011). This activity focuses on lithification processes. In the first trial of this experiment, other mineral salts were substituted for Epsom salt, with limited success. Subsequent trials *with* Epsom salt have proven successful. The variation of grain size between gravel and sand leads to "rocks" with different pore spaces, which directly connects student thinking to the next section.

Day 2: Hydrocarbon-Based Fuels and Formation

The students read about different types of hydrocarbon fuels (i.e., fuels that primarily contain the elements hydrogen and carbon) such as natural gas, coal, and crude oil. Reading resources included description of the chemical and physical properties involved in the formation of these fuels via different geologic processes. Petroleum and natural gas are the primary focus of this part of the unit since the two form through similar processes and therefore share chemical and physical properties. The burial of the organic matter followed by its transformation into the different fuels and their migration underground is also discussed. In order to demonstrate the importance of pore space to the formation of reservoirs, reference is made to the rock formation activity of the previous day. Demonstration can even be made with those artificial rocks by pouring vegetable oil through them. Alternatively, if the rock formation activity has been omitted, an investigation of pore space can be done independently (Women in Mining Education Foundation, 2007). Either activity directly leads to discussion of the relationship between energy-bearing shales, sandstone reservoirs, and capstone rock formations. The role of shales in formation and entrapment of these hydrocarbons was also explored. Students viewed a map of Pennsylvania that showed the locations of various petroleum and natural gas fields. The many byproducts of hydrocarbons and their impacts on our daily lives were also discussed.

This reading, demonstration and discussion lays the foundation for an oil-prospecting activity targeted at allowing students to use critical thinking skills to identify where oil is most likely to be trapped. Depending on the type of hydrocarbon, different hydrocarbon exploration techniques are used. The activity is adapted from one used by Furman in a Pennsylvania State University introductory geosciences course and is available from <http://www.paesta.psu.edu>; a simplified version that introduces the concept of hydrocarbon migration can be found online (Kluge, 2013). Students first applied the skills from the prior unit (Ellis et al., 2009) in determining the arrangement, folding, and faulting of rock layers on a cross section that includes possible drilling locations. Students then choose where to distribute their investments (\$50,000 in \$10,000 lots) between the six possible wells. In addition to drawing in the layers and choosing the wells, students must provide to their theoretical investors, a justification for why they should invest in those locations. In the end, each well was given a value in oil that would be obtained there and distributed amongst those investors based on the number of lots put into that well (number of \$10,000 investment increments). The winning student is the one who makes the most profit, which could mean choosing a well that produced less but that was selected by fewer other investors.

Day 3: Details of the Marcellus Shale Formation

Next, more specifics about the Marcellus Shale Formation, including its broad geographic expanse, were presented and discussed. Compared to conventional natural gas removal, the natural gas from the Marcellus Shale Formation needs to be extracted using a different technique. Recent technological developments in hydraulic fracturing (a.k.a. fracking) and deep lateral drilling have allowed extraction from this formation to be possible, as well as economically feasible. Students spent a day learning about and discussing the technology involved in reaching the Marcellus Shale. This involved use of a video about horizontal well drilling and hydraulic fracturing, which can be obtained from the Marcellus Center for Outreach and Research (2010). Students explore the factors that make the Marcellus Shale Formation so different from conventional natural gas reservoirs and why different methods and technologies are required for removal. The authors are fortunate to have access to a local expert on Marcellus Shale who speaks about the rocks, the extraction processes and related environmental concerns.

Day 4: Energy in the United States

Students explored individually the website explore.shale.org (Penn State Public Broadcasting, 2011), which provides information about how water is used in fracking. Students learn about the consequences of removing natural gas using different methods and technologies, also, including water quality concerns involving the chemicals used in the fracking extraction process. Students are encouraged to consider and document how extracting and using natural gas from Marcellus Shale compares to extracting and using other energy sources, which aided them when preparing the upcoming assignment described in Day 5. After individual examination, the students, as a group, discuss their findings. This activity tied into a reading initiative at Brightbill's school where students are taught a standardized way to read and annotate documents. Students were required to comment on 5 different aspects of the website, discuss them in small groups, and bring the biggest issue or two from each group to the whole class.

The final component of the unit focuses more broadly on the different types and uses of energy sources in the United States. Students learn how different sources of energy (petroleum, natural gas, coal, nuclear and renewable options) are allocated, or assigned, to certain sectors in the United States like transportation and electricity, and how energy consumption has changed over time. For example, Figure 1 shows how petroleum, natural gas, coal, renewable sources and nuclear energy are allocated to the transportation and residential electricity sectors. The United States is

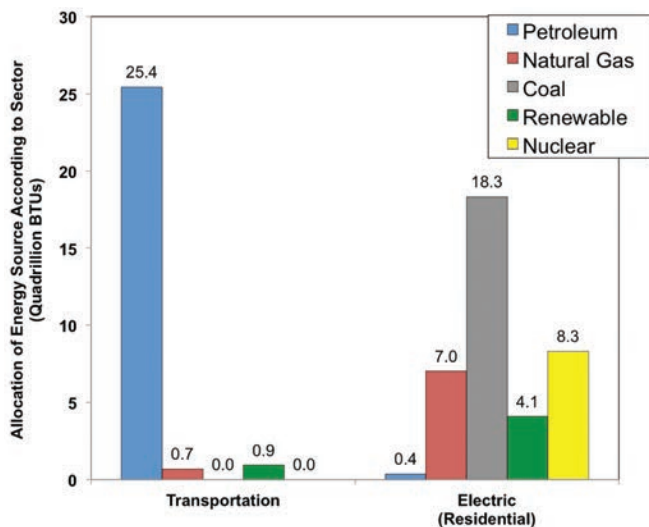


Figure 1.

most dependent on petroleum for transportation needs, while the residential electricity sector has a diversified portfolio of energy sources. The concerns of using fossil fuels (i.e., greenhouse gas emissions) and the present day and future impacts on society were discussed. Supplemental information for this discussion, including descriptions of coal, petroleum and natural gas and their geographic distribution can be found in Bembenic et al. (2012) and at <http://www.paesta.psu.edu/book/coal-and-energy-unit>

Day 5: Position statement on hydraulic fracturing

On the final day of this unit, students were asked to apply their scientific understanding of energy resource distribution and extraction to the social and political arena. Each student wrote a one-page position statement regarding the appropriate regula-

tion of hydraulic fracturing use in deep gas resource plays in the central Appalachians. The students were to choose a side and support it with at least 3 valid reasons. In Brightbill's class, letters were written to Pennsylvania State Representative, Scott Conklin, but writing to other policy makers is equally valuable, including state, local and national officials in the energy and environmental fields. This activity promotes clear communication of scientific ideas, and has, for maximum impact, been implemented successfully as an assignment between science and language arts teachers.

Conclusions/Lessons Learned

This week-long unit regarding the Marcellus shale integrates several different strands of Earth science learning, from sedimentary processes to formation of hydrocarbon resources which in turn are used as some of our primary sources of energy. It also opens the door for students to have informed opinions and discussions surrounding issues of societal and economic importance. Students completing this unit will learn to explore the science behind local political issues that play into national policy in the energy and environmental arenas. At the end of the unit, the students are empowered to develop a personal opinion based on, and supported by, factual and scientific evidence. It is important that these assignments be graded on the basis of the quality of evidence-based reasoning employed, not on the individual student's opinion, so that the fundamental difference between prejudice and fact-based argumentation is preserved. It is hoped that students who master this skill in middle school will be able to translate the experience to other politically-charged areas of their lives.

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About the Authors

Meredith Hill Bembenic is a post-doctoral research associate with the Earth and Space Science Partnership at Penn State University, University Park, PA. In 2011, she completed her PhD at Penn State in Energy and Mineral Engineering with a focus in fuel sciences. Meredith can be reached at mah339@psu.edu

Bryan Brightbill is a teacher at Park Forest Middle School in State College, PA. He is in his 6th year of teaching, having obtained a MEd in Curriculum and Instruction with a science education emphasis from The Pennsylvania State University in 2008 and a BS in Geosciences from PSU in 2005. Bryan can be reached at bkb13@scasd.org

Seyed Mehdi Kamali Shahri is a PhD student in the Department of Energy and Mineral Engineering at Penn State University, University Park, PA. He has received his BS and MS in Chemical Engineering and is currently working on an environmental project. Mehdi can be reached at suk251@psu.edu

Tanya Furman is a Professor of Geosciences and Assistant Vice President and Associate Dean for Undergraduate Education at the Pennsylvania State University. Her scientific research uses the geochemistry of volcanic rocks to understand global tectonic processes. Tanya can be reached at furman@psu.edu

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Exploring Regional Climate Patterns and Generalizing the Results to Enhance Deep Conceptualization

*Bryan Brightbill,
Park Forest Middle School*

<http://simpleclimate.wordpress.com>. Credit: PNNL

Abstract

An understanding of climate science and the processes that control Earth's past, present and future climate is increasingly important for students both as potential scientists and as future decision-makers in our society. Before students can begin grappling with the concept of anthropogenic climate change, they must build the necessary vocabulary and background knowledge for participating in meaningful discussion about the natural climate system. This article describes a 1-2 week unit on the factors influencing regional climate, focusing on student abilities to describe data, generalize the trends they see, and make predictions justified by their data.

Introduction

Context and Development

This unit is intended to be used as part of a larger middle grades Earth science curriculum. The typical sequence for Earth science that has been done with this lesson begins with geology and geomorphology, looking at the local landscape in terms of the rock types present and their erosional behaviors (Ellis et al., 2009). Next is a transition to a brief natural resources unit on oil and gas (Bembenic et al., this issue) which provides a jumping off point for discussion of climate change. In this discussion students have always recognized their own need for greater understanding of climate in general before they can address climate change. This self-reflective recognition is the transition that leads the class into investigating how climate varies around the globe and the causes of these variations. Following this investigation, the class returns to a discussion of climate change, traditionally in the form of a well-researched debate regarding the causes and effects of global climate change.

The original form of this unit was inspired by a plate tectonics activity designed for a hypothetical planet that was introduced in an upper-level Earth history class at the Pennsylvania State University. The activity was originally envisioned as an applied way of helping students remember the climate regions and their characteristics. Following the author's participation in Earth and Space Science Partnership (ESSP) workshops with a focus on using the Claim-Evidence-Reasoning (CER) framework of McNeill & Krajcik (2012), the purpose and method of this unit were redesigned. The unit

now emphasizes student efforts at making claims and predictions based on data and supporting them with logical and reasoned discourse.

Unit Components and Implementation

Introduction

While this unit could creatively be positioned in many ways within the curriculum, in the author's classroom it is nested between units on energy resources and climate change, serving as the transition between the two. The first day following completion of the energy resource unit begins with a brief discussion of climate and climate change, eliciting what the students already know or think about the two terms, and concludes in a class brainstorm of the questions that need to be answered in order to begin to understand climate change. Inevitably some variation of these questions arises: "What causes/affects climate?" and "Why is climate different in different places?" These are questions that the students can recognize as being essential to their ability to understand and discuss climate change, and the investigations begin.

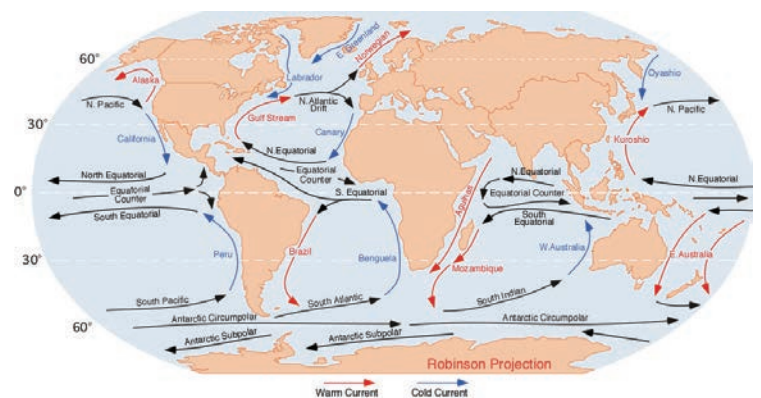
In order to discuss the phenomena that cause climate to vary geographically, it is necessary to adopt a classification system. Without a mechanism of generalizing the regional climate characteristics on a global scale, students easily become overwhelmed and unable to investigate in a consistent manner the factors that lead to these variations. For simplicity the organization included in the Pearson Prentice Hall textbook *Science Explorer: Weather and Climate* was used (Brooks Simons, 2007). This system classifies Earth's climates into 5 regions (Tropical Rainy, Dry, Temperate Marine, Temperate Continental, Polar) that are subdivided into a total of 12 climates, including one specific to mountain elevations that does not belong to any of the 5 larger regions.

Step 1: Noticing Trends in Air and Ocean Circulation

The first step in investigating the complexities of climate comes in trying to understand the fluid dynamics of atmospheric circulation. Prevailing winds play a major role in regional climate, and are caused by interaction between the large, latitude-based convection cells and the Coriolis Effect that results from Earth's rotation. An understanding of the generation and structure of the Hadley, Ferrel and Polar Cells is essential background to the study of Earth's overall climate system, and is particularly relevant to predicting the existence and direction of prevailing winds. The students must be able to refer to this information in order to build their explanations later in the unit. While there are inquiry-based options available for both of these topics, for this unit they are taught through direct instruction to establish common ground among the students and to reserve their creative energy for the subsequent activity.

Once the students are familiar with the Coriolis Effect, they are given a world map displaying ocean currents (see Figure 1) and asked to explain both the pattern of currents and the reason why some currents are warm and others are cold. This task is completed as a brief writing assignment where the students are prompted to make claims that address two specific questions: (1) Why do ocean currents flow the directions that they do? and (2) Why is an individual current either warm or cold? They must support each of the two claims with reference to actual currents on the map and provide a scientific explanation for what makes their claim valid (emphasizing the CER framework). The goal of this task is for students to recognize the generally clockwise rotation in the northern hemisphere, the generally

Figure 1. Map of world ocean currents (<http://blue.utb.edu/pauligj/geog3333/lectures/physgeog.html>)



counterclockwise rotation in the southern hemisphere, and the movement of warm currents away from the equator and the cold currents away from the poles.

Latitude, altitude, geography and proximity of large bodies of water all impact regional climates and recognizing these effects will contribute to student understanding of climate in general. There are various ways of addressing each of these, and in this curriculum these factors have generally been taught through a mix of discussion and demonstration. Latitude is classically demonstrated by shining the beam from a flashlight directly onto a board and tracing the outline of the light, and then shining the light from the same distance but at an angle to demonstrate that the same amount of light is spread out over a greater area when the sun is at lower angles, which leads both to cooler weather at greater latitudes as well as the variation between seasons as that angle changes (<http://tinyurl.com/bkxhs3s>).

Students investigate altitude and geography directly, as they document the locations of deserts in relation to mountain ranges and the existence of highland climate regions. The significant effect of proximity to large bodies of water can be shown using heat capacity lab exercises or demonstrations (See “A Day at the Beach” at this link: <http://tinyurl.com/aw4l26x>). A second effective method is to show a weather map that represents graphically the temperature buffering effects of proximity to water.

Step 2. Noticing Features that Define Climate Regions

The significant learning in this unit comes as students are asked to create generalizations from a diverse suite of data and then apply those generalizations in a new context. Students are asked (either in pairs or in small groups) to list the 12 types of climate as listed in the textbook (Brooks Simons, 2007) and describe where they *generally* occur. They are given the following instruction:

List the 12 types of climate and describe where each tends to occur. This can mean various things, but generally speaking you should address whether each climate:

- *Tends to be on just one side of a continent*
- *Tends to be next to or away from water/oceans*
- *Is influenced by warm or cold ocean currents*
- *Is influenced by an interaction between geography and the prevailing winds*
- *Tends to only exist at certain latitudes*
- *Tends to occur only within certain elevations*

The students typically converge around 3-5 location characteristics for each type of climate. Given the previous instruction in the unit, students have traditionally been very successful in forming these generalizations through discussion with their partners or in their groups. When students struggle, the Mediterranean may be used as an example to work through as a class. This type of climate has very specific criteria: it occurs between 30 and 40 degrees north or south latitude and on the west coast of land masses at those latitudes. Students may at this point also begin looking for the factors (cool ocean currents, prevailing winds moving over land from the ocean) that produce the regional climatic features, but they are not asked to furnish that information until the application and justification section.

Application and Justification

Once the students have a set of criteria of their own making for determining the climate region that would appear in any given geographic location, they are given a hypothetical planet with a different distribution of landmasses (see Figure 2). The students are informed that the atmospheric and oceanic circulation processes on Earth work the same way on this planet and therefore the only difference is the location of the continents. As a class, students decide on names for notable

geographic features (continents, oceans, mountain ranges) in order to facilitate discussion of climates on the alien planet. They are then asked to apply their knowledge of prevailing winds and ocean currents to mark those winds, warm currents, and cold currents that would likely form on this planet. An alternative approach to developing a hypothetical arrangement of continental masses is to employ paleogeographic plate tectonic reconstructions (<http://www.scotese.com/>) that may have particular significance for a specific region or time period.

Once all of the winds and currents are indicated, and the geographic features are named, students must identify one location on this planet for each of the twelve climate regions. This selection must be based upon the generalizations about each region that they had derived earlier. They must also justify the choice of each climate region in one or two sentences to explain their reasoning. Working in groups, students complete the map, while the reasoning statements are done independently after the map is completed. This step ensures that each member participates and develops an understanding of the material.

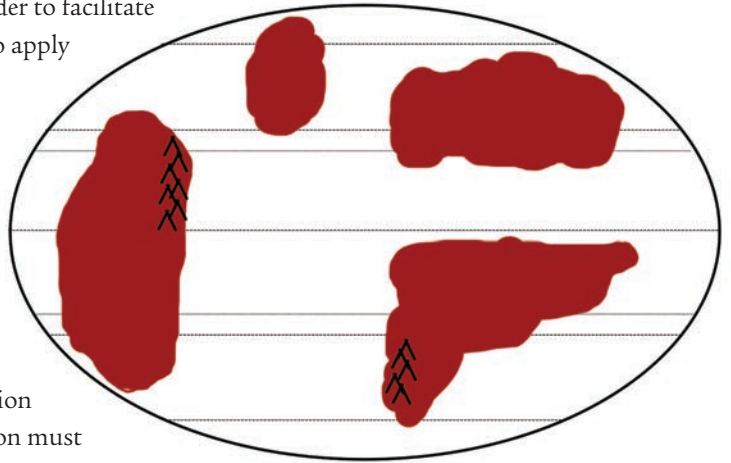


Figure 2. Alien planet map provided to students for labeling and identification of climate regions.

Grading

The map and the documents containing the geographic justifications serve as the final assessment for this short unit. The author works through the process along with the students as a demonstration every year. This joint effort creates an ‘answer key’ in hand once the maps are submitted, but because there is no unique solution this map is not the sole criterion on which the assignment is graded. The grade comes principally from the justification provided for each region. If a group’s submission for any given region does not match the teacher’s conception of this alien planet, but the members of the group provide a solid justification based on the evidence on the Earth’s climate map, they receive full credit. On the other hand, if a student’s reasoning is poor but the region is located in the same place as on the teacher map, that student receives only partial credit. Provided by the author, the following examples illustrate this grading system:

Example full-credit (3 pt.) explanation: Located on the east coast of Katniss is the humid subtropical climate region. This region experiences hot summers and cool winters. This climate region is influenced by the warm ocean currents which cause the temperature in the summer to get hot and the temperature in the winter to stay mild.

Note the description in the above example of how the warm ocean currents influence the nearby land. This is the type of reasoning that leads to full credit being awarded.

Example partial-credit (2 pt.) explanation: The wet humid subtropical climate is found from 20-40°, and typically above the tropics. It is on the southeastern coast of Brightville, and the middle eastern coast of Harperstan. This climate is found on east coasts, adjacent to warm currents. Prevailing winds do not affect this climate.

This explanation lacks a description of the role of warm currents, saying only that they are adjacent. The location given for the climate is reasonable, as are the trends, but adequate reasoning is lacking.

Example low-credit (1 pt.) explanation: The humid continental region was located on the Northeastern coast of Jeffathotmaildotcom near the Donkey Teeth Mountains. It gets high temperatures of 10°C and -3°C and lower in the winter. It is humid in the summer and cold in the winter.

About the Author

Bryan Brightbill is a teacher at Park Forest Middle School in State College, PA. He is in his 6th year of teaching, having obtained a BS in Geosciences (2005) and a MEd in Curriculum and Instruction with a science education emphasis (2008) from The Pennsylvania State University. Bryan can be reached at bkb13@scasd.org.

This example gives a location for the climate, but provides no justification or explanation whatsoever. Even though the location is reasonable, only 1 point is given for this response.

Example no-credit (0 pt.) explanation: West side of continent and northern side of continent. Hot summers cold winters near equator and is near cold ocean currents. Located on Normanland.

The above description earns no credit, as it includes incorrect information and lacks explanation. In addition, the poor writing quality renders this answer unacceptable for credit.

Conclusions

This activity has resulted in an appreciable difference in the ability of the author's students to discuss climate and begin to understand its complexities. This project also provides students with an excellent opportunity to exercise their skills in using reasoning to justify claims by making reference to solid evidence. The unit offers a great deal of flexibility for the teacher in choosing how to address each of the factors affecting climate. In this way, students are better able to make connections both within and across the curriculum and become poised to become informed citizens and decision-makers.

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The Power of a Hurricane: Using Memorable Storms to Teach Inference and Graphing Skills

*Greg Collins, Southern Lehigh High School
Eliza Richardson, Department of Geosciences,
Pennsylvania State University*

Abstract

Using real-time or near-real-time data in the classroom can form the basis for exciting guided inquiry lessons that build necessary scientific thinking skills. Choosing data from recent newsworthy events also motivates students to learn because they feel personally connected to the observations surrounding such events. The lesson presented here challenges students to collect a variety of types of near-real time authentic meteorologic data associated with a memorable hurricane of their choice, to decide how to best display that data to facilitate interpretation, and finally to interpret the multiple datasets in order to draw conclusions about how meteorological conditions change as a hurricane approaches and passes by a weather station.

Introduction

Twenty-first century skills have been a recent area of focus for schools around the globe, and for good reason. Technological literacy continues to rise in importance in the job market, and as information becomes more available the ability to draw conclusions from data is becoming more prized. Working with real-time data in inquiry-based exercises develops necessary critical thinking skills as identified by the National Science Education Standards (NRC, 1996) and also can engage students by giving them the opportunity to analyze timely and personally relevant data (e.g. the various “Remote Sensing Laboratories” described by Moore et al., 2013). For high school Earth science teachers, this change in focus presents a great opportunity. While most students in the class will likely not become geologists or meteorologists, they will all need to be able to make inferences and present data. Earth science is unique among the sciences in terms of the number of passive observatories that collect data and make it openly available to the public. Therefore, Earth science lessons that take advantage of such datasets are well-positioned to help students develop these interpretation skills, adding to the relevance of the class and motivating students to learn (Mulvey and Bell, 2012; Wildeboer, 2012).

Also relevant and motivating to students are news reports of local, national and global interest. The devastating tsunami that struck Japan in 2011 provided such a “teachable moment,” as did the eruption of Iceland’s Eyjafjallajökull in 2010. More recently for residents of the United States’ east coast, Hurricane Sandy proved to be an invaluable opportunity to capture students’ attention and to pique their curiosity about meteorology.

The lesson presented here, which involves data analysis of a memorable hurricane, is both relevant and content-rich. It has been taught, as presented, as a guided-inquiry exercise to college-bound juniors and seniors as part of a unit on hurricanes. It asks students to access publicly available data and generate graphs to make trends readily apparent. Students are provided with the location of the data repository to be used in this lesson, as well as the means to access it, but they must choose which data to download and decide the best way to plot that data in order to be able to interpret the data and arrive at the answer to their question. This structured inquiry process is an important part of building the kind of mentally flexible framework called “multiple external representation” by cognitive scientists that aids in scientific learning progressions (Ainsworth, 1990). Students are guided to present their graphs in the format of a meteogram, which is a standard document depicting weather data over time, usually a 24-hour period. Students then use their meteograms as tools to aid in data analysis, where students identify trends and make inferences about hurricanes.

Goals

The three overarching goals of this lesson are:

- making inferences from scientific data
- plotting data
- learning how meteorological observations at a location change as a hurricane approaches and then leaves the region

The Lesson

To begin the lesson, students are presented with a question to stimulate their interest: “How could the location of a hurricane be determined without access to radar or satellite images?” After a brief brainstorming session, the students attack the general question by investigating a specific case.



Figure 1. The main website page for Plymouth State University's weather data archive.

Each student studies a historic hurricane of their choice, by analyzing the weather records of the storm. Several websites, primarily those of university meteorology departments, make data archives freely available online. Plymouth State University's website (<http://vortex.plymouth.edu/statlog-u.html>) provides an easy-to-search archive with hourly data for nearly two thousand cities in North America going back to 1998.

Students visit the archives and access the data for a station near their chosen storm on the day of the event. Because not all weather stations are able to report complete records during hurricanes, it may be beneficial to direct students to certain stations for a given storm. Once they have accessed the site, students will see the data in text format; they must copy and paste that text into a spreadsheet program such as Excel. At this point, some data formatting is required. If teachers have a concern about the ability of their students to format the data, they can pre-format the table and make a file available for their students.

Alternatively, for advanced students, to keep the authenticity of accessing the data online, consider providing a macro or short program that does the formatting for them.

Once students have the data in a usable format, they begin the graphing process. Meteograms include three separate graphs and several weather symbols, all plotted as a function of time, for a single 24-hour period. Meteograms do follow a standard format (see Figure 2), but students should be encouraged to experiment with different ways of displaying the multiple datasets they have acquired. Engaging in plotting experimentation is an important part of developing scientific

inquiry skills and it also helps students think about the importance of clear and coherent plots as scientific communication tools (Tufté, 2001). Students can be guided towards producing a meteogram in standard format, in which the first graph plots temperature, dew point and relative humidity on a single panel; the second graph shows both visibility and cloud ceiling; and the third plots barometric pressure. Also included are symbols for cloud cover, wind speed and direction, and precipitation. These symbols require drawing by hand, so a file can be provided to students with the symbols pre-drawn, or the students can annotate their completed meteogram after printing it.

Next, the completed meteogram is used to analyze the storm. Students can then be given a worksheet (for a sample worksheet go to <http://www.paesta.psu.edu/classroom/power-hurricane-using-memorable-storms-teach-inference-and-graphing-skills>) that asks them to identify trends with respect to time for the observations of temperature, pressure, cloud cover, and the other data. They are also asked to look for correlations among different types of data, for example, whether wind speed and pressure change simultaneously or whether the change in one observation lags the other.

When students analyze trends in wind, they are led back to the original motivating question about hurricane location. By looking at both wind speed and direction and applying their knowledge of the rotation of low-pressure systems, they can generate a claim regarding the position of the eye and support their claim with their evidence and reasoning. They are specifically asked to identify the time they believe the eye of the storm was closest to the weather station and the position of the storm at that time. Once students have generated their claim, they share their hypothesis with the teacher before checking their hypothesis against additional data.

The final step of this lesson is for students to investigate the actual path their storm took. Through an internet search, students can find maps for most historic storms. They then compare their claim about the storm's position to its actual movement and explain any possible causes for error in their claim. This activity leads into good class discussion of student results and any lessons and/or skills learned.

Conclusions

This lesson provides a fun way to teach several key science skills at once, making it both effective and efficient. Taught as presented in this article, the lesson is both rigorous and relevant for college-bound high school juniors and seniors. It can, however, be easily modified to serve other levels. For younger students or students with less developed graphing skills, it is appropriate to graph only certain key measurements or to access already-completed meteograms via the Plymouth State website for their chosen hurricane. In this implementation, students focus on analyzing the data without spending as much time on graphing.

For students who need a greater challenge, this lesson can be used to begin a unit on low-pressure systems. Assign groups to a certain storm but have each student in the group analyze the data from a different nearby weather station. By putting together information on wind speed, direction, and barometric pressure around a storm, student groups can discover some key characteristics of hurricanes before direct instruction, which would hopefully improve their understanding and retention.

As the Next Generation Science Standards are ushered in, there will be an increased focus on teaching science as process. The lesson presented here, works to grow the general, science skills of inferring and graphing while also building content knowledge through discovery.

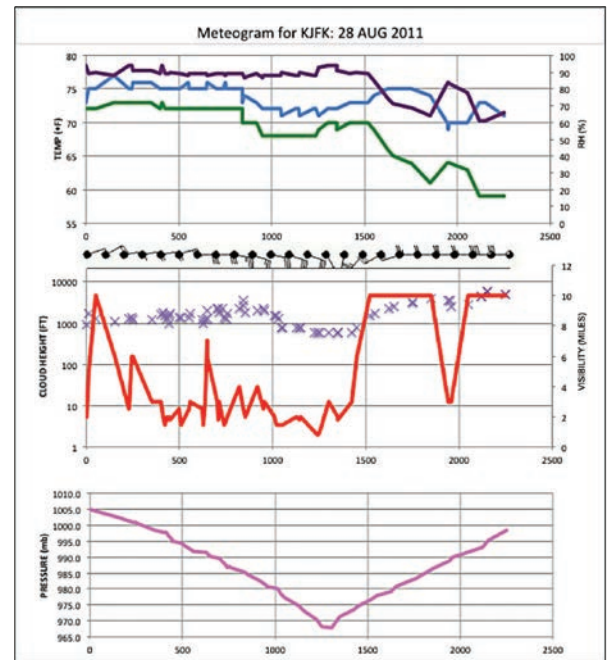


Figure 2. Sample 24-hour meteogram generated in this lesson for station KJFK (New York City). Top panel shows Temperature (blue) and dew point (green) in F° and relative humidity (purple) as a percentage. Middle panel plots cloud height (x's) in feet and visibility (red line) in statute miles. Bottom panel plots barometric pressure in millibars. Symbols in between the top and middle panel indicate wind speed and direction.

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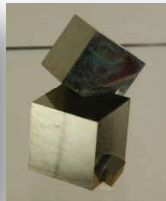
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About the Authors

Greg Collins earned bachelor's degrees in Physics and Mechanical Engineering from Wilkes University and an M.Ed. in Curriculum and Instruction from Kutztown University. He is a candidate in the M.Ed. in Earth Sciences program at The Pennsylvania State University. He is presently a science teacher at Southern Lehigh High School in Center Valley, PA, leading students in courses on natural hazards, energy, physics, and a survey of Earth science. Greg can be reached at collinsg@slds.org

Eliza Richardson earned her bachelor's degree in Geology and Geophysics from Princeton University and her PhD in Geophysics from MIT. She is currently an assistant professor in the Department of Geosciences and the director of the M.Ed. in Earth Sciences program at The Pennsylvania State University, University Park, PA. Her current research focus is on the spectrum of fault slip in subduction zones. Eliza can be reached at eliza@psu.edu

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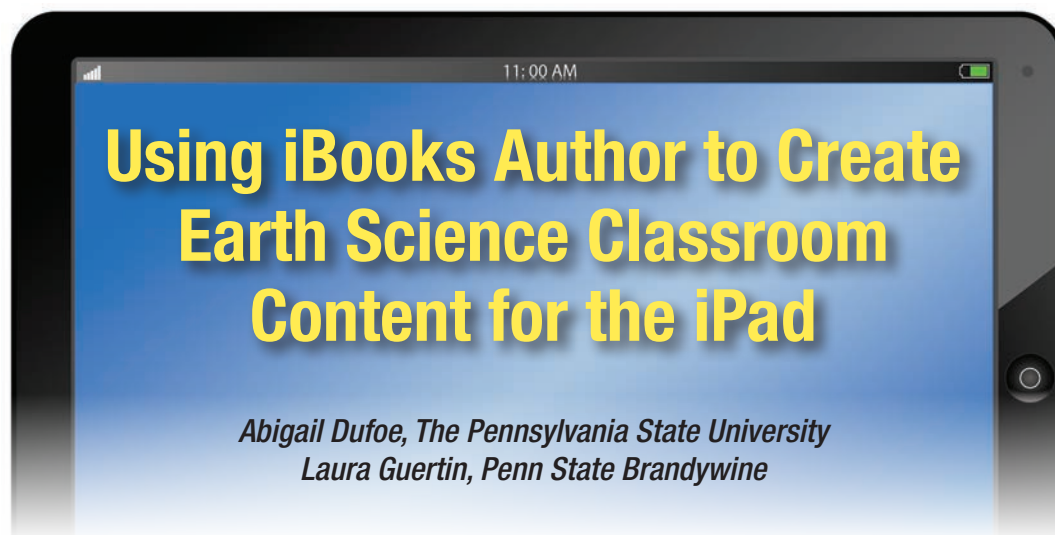


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Abstract

With Apple's freely available iBooks Author software, teachers have the ability to create customized iBooks for their students viewable on iPads. iBooks Author allows for the creation of content that is interactive and enhanced with multimedia, which can engage students in current and relevant Earth Science topics. Described here are two iBooks created as examples for use in middle school classrooms. *Controversies in the Hydrosphere* is a collection of case studies related to global water issues. *Deepwater Horizon Oil Spill* outlines the specific 2010 oil spill event in the Gulf of Mexico. iBooks provide the opportunity for Earth Science content to be presented via new technology as well as the creation of a different learning environment.

Introduction

The National Center for Education Statistics reports that only 29% of public school teachers are using Macintosh or PC computers as an instructional tool (Gray et al., 2010). However, there has been an increasing presence of iPads in the K-12 classroom, with Apple reporting in January 2012 that 1.5 million iPads are being used in schools (Kessler, 2012). With teachers acquiring iPads for personal and professional use, and many schools providing iPads and iPad carts for classrooms in place of outdated computer carts, the iPad now offers a portable, lightweight option for teaching and student learning.

One advantage of using iPads in schools is that iPads offer the availability of electronic classroom resources such as iBooks. An iBook is a digital resource available from Apple's iTunes store or from additional websites that can be downloaded onto an iPad via the iBooks App. The cost of an individual iBook can range from free to over \$20 each. Teachers can adapt iBooks to their existing lesson plans or create their own new classroom approach incorporating customized iBooks.

The challenge remains that although the technology is getting into the hands of students and teachers, freely available Earth Science iBooks and relevant digital materials are still lacking. This article describes how to use iBooks Author to create customized content for the Earth science classroom, then discusses two custom-made iBooks connecting to global water issues. The goal was to create iBooks that can be used in the middle school classroom by Earth science teachers. The iBooks are designed for classroom situations where teachers are able to connect an iPad to a LCD classroom projector and guide students through the projected iBook content. Alternatively, if enough iPads are available, students may work in teams or individually to read through the iBook, answer questions, complete worksheets, etc.

Methods

iBooks Author (see <http://www.apple.com/ibooks-author/>) is a free application available from Apple's App Store. The program requires Mac OS Version 10.7 or later and is only available for the Macintosh computer. The electronic books created by the iBooks Author program can only be opened on an iPad through the iBooks App. However, a completed iBooks Author file can be exported as a PDF file and read in any PDF reader on any computer platform. Note, however, that the interactive features of the iBook will not function in the PDF export.

Keeping the classroom audience in mind, each chapter in the iBooks was formatted with four sections: case studies, review quiz, discussion questions, and references. The content can be typed directly into the iBooks Author software, copied and pasted from any text-editing software, or "dragged and dropped" from a MS Word file. Review questions were created based on Bloom's Taxonomic Scale (Bloom, 1956 as updated by Anderson & Krathwohl, 2001), with the multiple-choice review quizzes on the low end of Bloom's Taxonomic Scale and the discussion questions towards the top of the Scale. The discussion questions were presented without the answers, so students would have to work their way through the responses. Answer guides for the open-response questions are not provided with the iBooks.

Photos and videos are provided as supporting media to the iBooks. To ensure free distribution of the completed iBooks, copyright-free images from Wikimedia Commons (<http://commons.wikimedia.org>) and Flickr were used. The Flickr images selected are under a Creative Commons license, and photographers are credited in the references for each chapter. Additional images in the public domain were used from the government agencies: NASA, NOAA, EPA and USGS. To gain access to the many quality videos that exist online, widgets for YouTube videos from Bookry (<http://www.bookry.com>) were utilized so that the online videos would stream and play in the iBooks.

In addition to the supporting photos and videos, interactive components of the books were assembled with widgets provided with the iBooks Author software. With the copyright-free images, image galleries were created that the user can swipe through as a slideshow. Multiple-choice review quizzes were also created that allow the user to check their selection immediately with the "Check Answer" button underneath each question and to see a final score upon completion of the quiz. Additional widgets were used from the Bookry website, such as the real-time Twitter feed viewer and a full-screen webpage viewer, both of which automatically update if the iPad has a live internet connection.

The completed books were saved as .iBooks files and made available on the PAESTA (Pennsylvania Earth Science Teachers Association) website (<http://www.paesta.psu.edu/ibooks-earth-space-science>) for free download. To download the books, the URL should be accessed from Safari on an iPad that already has the iBooks App.

Controversies in the Hydrosphere

The goal of *Controversies in the Hydrosphere* is to explore a variety of controversial issues regarding water on the planet. The hydrosphere is an integral part of Earth's interconnected spheres and features prominently in the Big Ideas of Earth Science (Earth Science Literacy Initiative, 2009). This six-chapter iBook begins with an overview of the Big Ideas, supplemented with embedded corresponding AGI (American Geosciences Institute) videos for each idea (from <http://www.earth-science-literacy.org/videos.html>). The second chapter reviews Earth's lithosphere, hydrosphere, biosphere and atmosphere, focusing on the linkages between these realms. Each subsequent chapter focuses on a specific water issue: aquifer depletion (chapter 3); freshwater chemical contamination (chapter 4); marine debris (chapter 5); and glacial melting (chapter 6). Each chapter is presented in a case study format that highlights the history of the issue, its current scientific and political status

(if applicable), and some solutions that have been generated by organizations such as NOAA and the EPA. The case studies include short, comprehensive multiple-choice quizzes, as well as critical thinking questions. The questions, presented in an open-ended format, focus on the Big Ideas, proposing solutions for rectifying the situation, and/or assignments specifically targeting an idea presented in the case study. These questions were created for discussion purposes and/or for individual responses. The iBook ends with a glossary of the terms that may be new or challenging for middle school students.

Deepwater Horizon Oil Spill

The goal of the *Deepwater Horizon Oil Spill* iBook is to provide a summary of the history and status as of November 2012 of the worst oil spill in the history of the Gulf of Mexico. This single-topic iBook starts by defining oil spills and reviewing different methods and technologies used to clean up spilled oil in ocean and freshwater environments. The text then presents specific details of the volume of oil spilled in the Gulf of Mexico over time. The case study explains the impacts of the Deepwater Horizon spill on the environment, economy and public health, and also explores the different audiences responsible for the financial remuneration and environmental restoration efforts. The iBook includes images, videos, external links to websites for further exploration and multiple choice and open-ended questions. Just like *Controversies in the Hydrosphere*, this iBook contains a multiple-choice review quiz and open-ended discussion questions as well as a glossary, time-lapse photo section of the spill, and supplemental links.

Initial Feedback

Neither iBook has been formally tested in the classroom. *Controversies in the Hydrosphere* was presented at the PAESTA conference in October 2012 and at the American Geophysical Union (AGU) conference in December 2012. Visitors to the AGU poster presentation were able to engage with the iBook on an iPad and view images projected on a large monitor. The iBook was positively received by conference attendees, which included classroom teachers and informal educators. Visitors were surprised and pleased to learn there is no charge for the final product. Some attendees asked where one could find a corresponding lesson plan for the iBook. Lesson plans were *not* developed so that teachers could adapt materials to their classrooms and use the iBook in a way that was appropriate for their instruction, either as a source of content to drive a classroom exercise or as a supplemental tool.

The iBooks Author software is intuitive for teachers to use to create their own iBooks with specialized content for their students. An iBook can be a multi-chapter book or cover a smaller, more focused topic. Teachers may also choose to create a textbook experience for a course, which can be easily and quickly updated so that content for students is always current. Additional iBooks continue to be created and are available through the PAESTA website to help provide teachers an engaging resource for Earth science instruction.

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About the Authors

Abigail Dufoe is a recent graduate with a bachelors degree in Media Studies and minors in Environmental Inquiry and Civic & Community Engagement, at The Pennsylvania State University, University Park, PA. She is beginning her masters degree in environmental studies and nature conservation journalism at the University of Montana in fall 2013. Abigail can be reached at abbey.dufoe@gmail.com

Laura Guertin is an Associate Professor of Earth Science at Penn State Brandywine, Media, PA. Her research involves studying how new and emerging technologies impact teaching and student learning in introductory-level Earth science courses at the university level. Dr. Guertin can be reached at guertin@psu.edu

Figure from Isaac Newton's "A Treatise of the System of the World" that Newton used to present his analogy between the motion of the Moon in its orbit around the Earth and a projectile fired from a high mountain. Image retrieved from a scanned copy of the book and made available through Google Books.

The Role of Gravity in Planetary Orbits

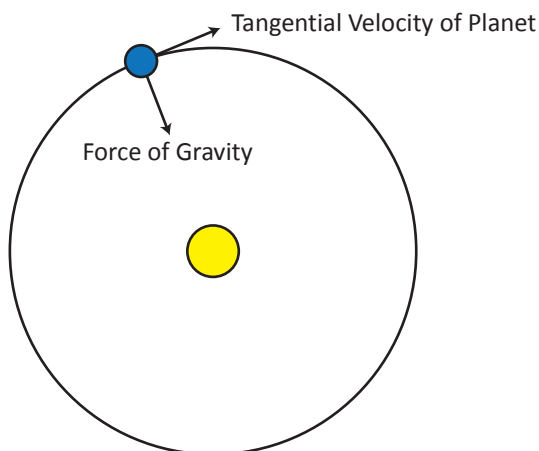
Alice Flarend, Bellwood-Antis High School
Christopher Palma, Department of Astronomy & Astrophysics, Pennsylvania State University



Abstract

Recorded interviews with students from grades 6, 11 and 12 in Reading, Pennsylvania and in the districts of Bellefonte Area and Bald Eagle Area both located in central Pennsylvania, consistently revealed that students had, at most, a superficial understanding of the roles both gravity and velocity play in planetary orbits. This level of understanding may reflect the Pennsylvania state standards for 10th grade students that unintentionally reinforce the misconception that gravity alone is responsible for planetary orbits. To address this shallow student understanding, the authors designed an activity for in-service teachers regarding the role that a planet's tangential velocity plays, along with that of gravity, in determining the orbit of an object. After the teachers investigated the required velocity for the orbit of a simulated planet around a simulated Sun, the content of their post-activity discussion revealed that the activity improved teacher understanding of the additional component of velocity, which should in turn improve instruction and student understanding.

Figure 1. Diagram of a planet in a stable orbit around the Sun, with both the gravitational pull of the Sun and the planet's tangential velocity vectors labeled. Not to scale. Drawn by C. Palma.



Introduction

The purpose of this article is twofold: (1) to share results of student interviews that corroborate misconception work of previous authors relating to the student understanding of the nature of planetary orbits; and (2) to share an in-service teacher professional development activity and suggestions for classroom instruction to improve student understanding of the roles of velocity and gravity in planetary orbits.

Classroom textbooks serve as one introduction for students to the science of planetary orbits. The description of planetary orbits in a typical textbook in grades 6-12 is accompanied by an image similar to Figure 1. The discussion accompanying the image typically explains that a planetary orbit requires two elements: the planet's **velocity** perpendicular to the Sun/planet line and the **gravitational force** of the Sun, which pulls the planet in the direction of the Sun, accelerating the planet in that direction. The combination of the planet's tangential velocity and the gravitational pull of the Sun creates the curved orbital path illustrated in Figure 1. Planets that are further from the Sun have a smaller tangential velocity since they experience a smaller gravitational force.

However, the Pennsylvania State Standards may contribute to misunderstandings about planetary orbits. Contrasting the textbook discussion of orbits with the statements in the PA state standards documents indicates that the standards appear to reinforce a shallow understanding of orbital motion. In the Pennsylvania Academic Standards for Science and Technology and Engineering Education (2010), standard 3.3.10.B1 reads in part, “Explain how gravity is responsible for planetary orbits”. This statement does not acknowledge the essential role that the planet’s velocity also plays in determining the orbit. The questions accompanying textbooks are written to directly address the standards and serve as a focus for a teacher’s instruction. Yet, at least one middle school science textbook had questions in the section on planetary orbits that focused exclusively on gravity and asked nothing about the planet’s velocity, even though the accompanying text correctly identified the role of velocity. The standards and the textbooks together are reinforcing the incomplete idea that gravity alone is responsible for planetary orbits.

Student Understanding of Orbits

Part of a research effort through the Penn State Earth and Space Science Partnership (NSF Award #DUE-0962792) is to probe how students develop an increasingly sophisticated understanding of topics in Solar System astronomy. The authors have been interviewing thirty-eight students from grade 6 through 12 in central Pennsylvania (Plummer, Flarend, Palma, Rubin, & Botzer, 2013). Participants were asked a series of questions about the nature of the Solar System, including questions about the composition of the planets, the motions of objects in the Solar System, the reasons for those motions, and the formation of the Solar System. Some specifics about the interviews are given below. Shortly after beginning analysis of the first set of interviews, it was apparent that students not only exhibited misconceptions but also had a hard time answering any questions about planetary orbits that went beyond description.

When asked about the reason that a planet stays in orbit around the Sun, over 70% of the interviewed students stated simply that gravity keeps the planets in orbit, an answer that does imply some level of understanding of the nature of planetary orbits. However, when the students were probed more deeply to find out what they understood about exactly how gravity causes the orbits, it was found that they often could not say much more than “gravity is what keeps planets in orbit”. Interestingly, the students often had no explanation about why the planets did not crash into the Sun, even though the Sun’s gravity attracted the planets towards it. Some explanations that were offered involved non-normative ideas such as gravity being both an attractive and repulsive force, the presence of another force at work in the Solar System, or the idea that the planets cannot crash into the sun simply because then there would not be a Solar System.

The interviewed students were also asked a series of questions involving hypothetical situations with a test mass (e.g., “what if there were a small rock...”) at different locations, including at rest near a planet. The students did not show any understanding that this initially motionless test mass should behave differently than one with tangential velocity. Since the test mass is initially at rest, it would immediately be pulled gravitationally towards the planet instead of achieving an orbit. This was meant as a further probe about why the planets do not crash into the Sun. While, some of the interview subjects were sixth graders, who might not fully understand the question, the answers from 11th and 12th graders in a high school physics course were often qualitatively very similar to the answers of the 6th grade students’.

The hypothetical test mass interview questions also revealed misconceptions about the behavior of gravity with distance similar to those found by Palmer (2001) and Williamson & Willoughby (2012). For example, many students interviewed appeared to share the “boundary model” misconception

described in the latter article, where they believe that outside of some boundary, such as the Earth's atmosphere, somehow gravity is zero. While these new interviews revealed correspondence with the misconception work of these cited authors, none of the studies asked questions about the nature of planetary orbits as did the ones included in the authors' interview protocol. Thus, these interviews reveal new understanding about student thinking regarding planetary orbits, not found in the literature.

Overall, only 10% of the students used the planets' velocities in their explanation of planetary orbits and fewer than 25% could describe the behavior of gravity with distance. Ultimately, these interviews provided enough evidence to support the hypothesis that students have at best, only a superficial understanding of the role of gravity in supporting planetary orbits and almost no understanding of the additional need for a tangential velocity.

Outline of a Lesson for Teaching The Role of Gravity in Planetary Orbits

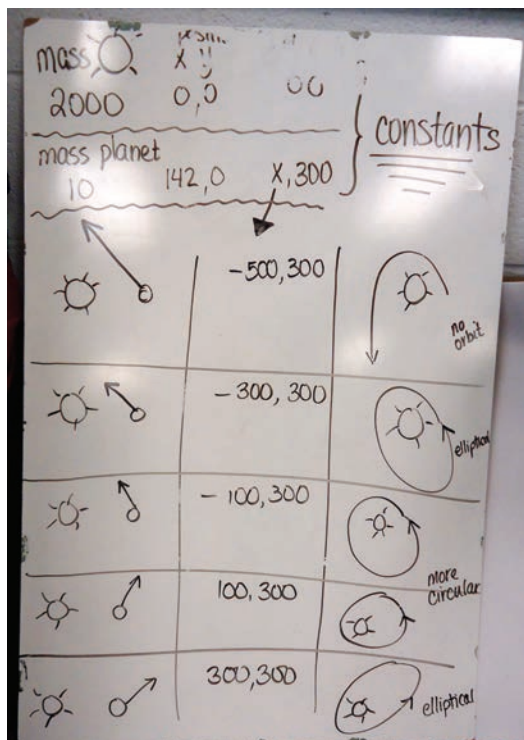
The interview data, documents that students do not seem to fully understand that that orbits are a balance between a planet's motion and the Sun's gravity as opposed to being solely caused by the Sun's gravity. Specifically to help teachers address this concept, an activity was designed and included in a summer 2012 professional development workshop on Astronomy for in-service teachers.

The workshop activity used the Physics Education Technology (PhET) simulation: "My Solar System" (<http://phet.colorado.edu/en/simulation/my-solar-system>), created by science content specialists, education specialists and software engineers at the University of Colorado at Boulder. This simulation displays the path of up to four astronomical objects as they interact via Newtonian gravity. The mass, initial velocity and distance between these objects can be specified either numerically or by manipulating screen icons. The teachers in the workshop (or students who would do a similar activity in class) were able to gather both quantitative data such as orbital period and qualitative data such as the orbital shape. The versatility of the simulation allows for exploration of multiple phenomena. An advantage to using the PhET simulations is that they can be downloaded to be used offline, so no class internet connection is required.

During the workshop, the activity began with a general exploration to familiarize the participants with the simulation. As the participants explored the simulation's controls, workshop facilitators guided them to explore the conditions needed for a less massive object (e.g., a planet) to orbit a more massive object (e.g., the Sun). The participants worked in small groups and experimented with changing the properties of objects in their simulated solar system, in order to make orbits of multiple shapes and sizes. The simulation is general enough that it can simulate, for example, binary stars of nearly equal mass. However, since the objective was to focus on conditions like those in the Solar System where there is a massive Sun orbited by significantly lower mass planets, they were provided with suggested initial conditions. A minimum mass of 2000 kg for the central body and 20 kg for the satellite were specified so that the motion of the central body would be minimized, as it is in our own Solar System. Other than this, the parameters were left open for them to experiment on their own. After gathering data, each group of teachers recorded on a large (2'x3') whiteboard the different parameters they tested and whether they were able to achieve a stable orbit of their planet around their Sun in the simulation.

Figure 2. Photograph of a whiteboard from the 2012 workshop that shows the teachers' visualization of their data as they reported out to their peers during a "board meeting".

Photo by Alice Flarend.



Following Desbien (2002), the participants were asked to share their findings by displaying their boards to each other in a “board meeting” (Figure 2). This board meeting technique is useful when there have been different investigations occurring (e.g., different parameters being explored by each group). A board meeting allows for efficient information sharing and critiquing as well as discussion of general trends across a variety of data sets. During the debriefing session, the participants noticed that different velocities led to variations in both the shape and stability of an orbit.

After getting a broad overview of the patterns seen by varying multiple parameters, the teachers engaged in an in-depth exploration of a specific parameter. For example, one group investigated how the velocity needed for a circular orbit changed with the distance from the central body, and another investigated how the velocity varied with the mass of the central body. The results were again displayed on whiteboards and the participants critiqued each other. By the end of the board meetings, the teachers saw patterns that showed how orbits required a delicate balance between velocity and gravitational pull: too little velocity led to an impact, while too much velocity led to an escape of the satellite from the gravity of the central body.

A Pedagogical Framework for this Activity

During this workshop, the teachers were also introduced to the “Claim, Evidence, and Reasoning” (CER) framework of McNeill and Krajcik (2012), so that they might in turn employ this methodology in their own instruction. The purpose of this framework is to advance the scientific writing skills of K-12 students as well as to emphasize that scientific conclusions are based on data and theoretical models. These science process skills are part of the new Framework for K-12 Science Education and the Next Generation Science Standards (2012). Teachers were required to employ this pedagogical technique by articulating a claim about the nature of planetary orbits. They used their work with the simulation to provide evidence that supported that claim, and then relied on their prior scientific knowledge about gravity to provide scientific reasoning for how their evidence supported their claim. Each group of four teachers wrote statements on their whiteboards with their group’s claim, evidence and reasoning. They then shared their work in a final board meeting where each group provided the others a chance to give feedback. The discourse among the teachers following this activity was particularly rich. For example, by comparing the data used as evidence, the teachers found for themselves that planets that are more distant from the Sun can achieve stable orbits with smaller tangential velocities. They then reasoned that this shows that the force of gravity falls off with increased distance, even though this particular point about the nature of gravity was not emphasized at any point previous to the concluding discussion.

Conclusion

The experience with this research project, and subsequent efforts in a teacher professional development workshop, have reinforced the importance of incorporating data on student learning as feedback that directly informs instruction. The instruction necessary for students to understand planetary orbits at more than a very superficial level, requires a focus on the balance between tangential velocity and gravity, and not just the presence of gravity alone, as indicated by the Pennsylvania standards. The authors feel strongly that this disconnect between scientific theory and educational standards needs to be addressed by a rich professional development experience for teachers, and classroom instruction for students. In this article, the authors presented one way in which this goal might be accomplished. It is expected that the disconnect between Pennsylvania standards related to gravity and planetary orbits is not widely recognized by teachers or curriculum developers. The cohort of teachers who attended the 2012 workshop have reported that activities like the one detailed here, have improved their content knowledge in Solar System astronomy and altered their instructional practice. One teacher reported that her students have impressed her with

their level of understanding following her revised astronomy instruction; this anecdotal remark is supported by classroom video of students asking questions that reveal expert understanding of planetary orbits. This exciting result suggests that teacher professional development efforts in Solar System astronomy can lead to real changes in student understanding.

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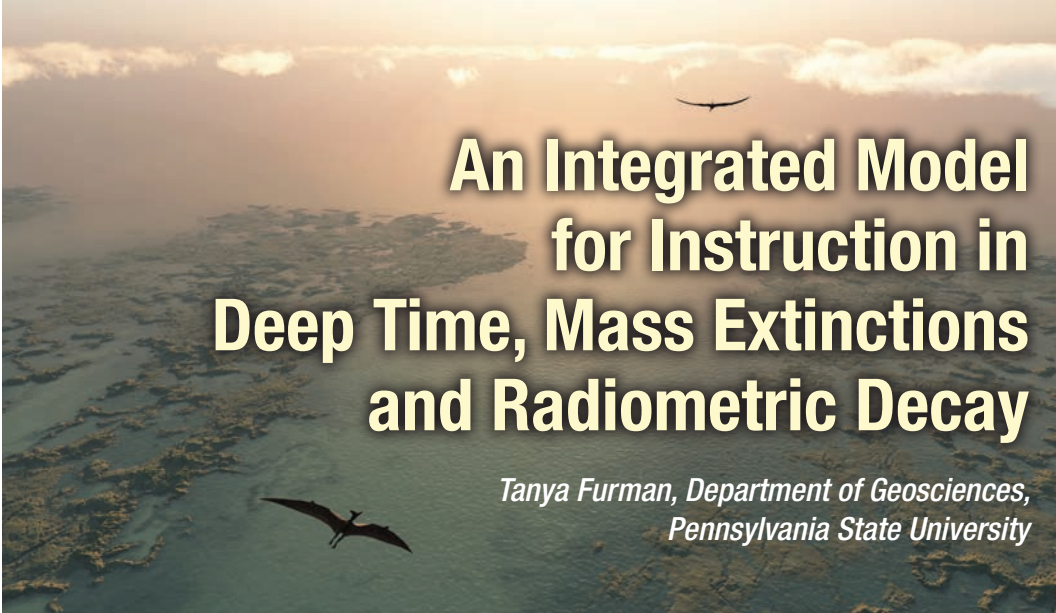
About the Authors

Alice Flarend works as a veteran high school physics teacher at Bellwood-Antis High School and is a National Board Certified Teacher. She is a Physics Teacher Resource Agent of the American Association of Physics Teachers, and is also a doctoral candidate in the Science Education Program of Curriculum and Instruction at Penn State. Her research interests involve in-service teacher professional development. Alice can be reached at amf@blwd.k12.pa.us

Christopher Palma is a Senior Lecturer of Astronomy and Astrophysics at Penn State, and he also served recently as the Associate Director of Outreach in the Eberly College of Science. His teaching interests include informal science education for K-12 students. His research interests include the study of globular clusters, dwarf galaxies, and stellar populations. Chris can be reached at cpalma@astro.psu.edu.

Why should I open and read my NESTA ENews emails?

NESTA's monthly *ENews* provides brief summaries of stories and projects that have a direct link to the Earth Sciences and or the teaching of Earth Science. Many of these short articles provide links to more information or complete websites that those interested can follow. The *ENews* also contains information regarding teacher opportunities for research, professional development, and even grants. The reader will also find a calendar with items that have time critical information or may be occurring later that month or the next month. Each month, the *ENews* provides links to a selected state's Earth Science sites. For example in the November 2012 issue we focused on Earth Science resources in Arizona, the state where the 2012, December NSTA Area Conference was held.

An aerial photograph of a coastline with a pterosaur flying in the sky. The text is overlaid on the image.

An Integrated Model for Instruction in Deep Time, Mass Extinctions and Radiometric Decay

*Tanya Furman, Department of Geosciences,
Pennsylvania State University*

Abstract

Within the scientific community there is nearly universal consensus about the age of the Earth, but neither the time scale nor the methodology by which it was determined is intuitively familiar to teachers and learners of Earth science. Contextualized instruction about rocks, minerals and fossils can develop greater understanding by making explicit linkages among deep time, the development of the geological time scale, mass extinctions and the techniques used to measure the ages of rocks. This approach also integrates numeracy and literacy skills across the curriculum and can be used for differentiated instruction within a single classroom or across grade levels.

Introduction: Deep Time and the Age of the Earth

Deep time, or geologic time, is fundamental to understanding Earth processes. Most geological events happen slowly and over such extremely long periods of time that are outside the realm of human experience and observation. This foundational concept was first fully articulated in the 18th century by James Hutton (1788) and today still provides challenging opportunities for instruction. While scientists readily agree that the Earth formed ~4.5 billion years ago, understanding the evidence used to establish this age requires detailed knowledge of solar system formation or great faith in scientific observations and interpretations that appear impossible to verify. Not only are the time periods involved disconcertingly long, but the processes of radiometric decay (used to calculate the age of an appropriate rock or mineral) and planetary accretion (used to justify the choice of meteorites as analogues to Earth) are typically introduced in middle or high school, years after the introduction of rocks, minerals, dinosaurs and geologic time. This article explores an alternative approach to teaching this suite of topics that helps students go beyond memorizing unfamiliar and disconnected names, and replaces them with a historically and scientifically sound reasoning scheme to scaffold understanding of geologic terms and processes.

Research has consistently found that learners of all ages typically grasp and retain the overall *sequence* of biological events in Earth history, from the appearance of first life to the rise of the dinosaurs and finally the advent of humans (Trend, 1998, 2000, 2001; Dodick and Orion, 2003; Libarkin et al., 2007; Guertin et al., 2011). Other biological events, such as the origin of vertebrates or the extinction of the dinosaurs, are less frequently mentioned by students and indeed may generate

substantial confusion. Further, the dates at which any particular biological events occurred are poorly recollected. For example, Guertin et al. (2011) found that among a group of Pennsylvania teachers from grades 4-12 at a workshop on Plate Tectonics, while over 90% knew the correct sequence of the above events, only 29% knew the date at which the first humans appeared and only 18% could provide the date at which the dinosaurs first evolved. Without knowing the actual ages of significant Earth events – biological or geological – it becomes impossible to facilitate learning about Earth history and processes, as well as sending a message that quantification is neither important nor relevant to scientific understanding.

Evidence for the age of the Earth

There is no direct scientific evidence from which we can easily explain the age of the Earth. The oldest rocks on our planet, found on the cratonic portions of Australia, Africa, North America, Asia and Greenland, are between 3.8-3.9 billion years old. Sedimentary minerals within these rocks have been dated to 4.1-4.2 billion years, but both the rocks and the minerals provide us with a minimum age only: Earth must have formed and cooled substantially before sedimentary processes became established. Our evidence for the age of the Earth comes from study of meteorites. Multiple isotopic analyses of some ~70 meteorite samples yield ages that cluster around 4.55 billion years, and that value is adopted for the Earth as well (e.g., Stassen, 2005). Many assumptions are invoked as we establish the age of the Earth, and while they are scientifically valid and appropriate they are not intuitively apparent to students and are often omitted in classroom discussion. A consequence of this omission is that it opens the door to non-scientific explanations by asking students to accept unsubstantiated and untestable claims. Assumptions involved in determining the age of the Earth include the following: (1) meteorites formed contemporaneously with our planet, (2) meteoritic materials have not undergone material recycling through plate tectonic processes, (3) while individual meteorites are not compositionally like the Earth, a weighted aggregate of meteorites does share Earth's bulk composition, (4) elements such as Pb and U were distributed evenly in the solar nebula. While full discussion of these assumptions is likely beyond the scope of the middle school classroom, acknowledgement of the scientific approach is important to include.

Improving classroom understanding of radiometric decay

Classroom discussions of geologic time are often presented in the context of radiometric decay. Many laboratory activities that introduce this topic involve candy pieces, and assume that students already have an understanding of atomic structures. Application of these activities to geologic processes is challenging, because most of our useful information comes from atoms that decay to generate atoms of a different and unfamiliar element (e.g., K-Ar, U-Pb, Sm-Nd, Rb-Sr) and this process is difficult to mimic with candy. In contrast, ^{14}C dating is more accessible to student learning, because the root element is already familiar and remains constant. The reliance on ^{14}C introduces two fundamental difficulties that are worth recognizing. First, the time scale of carbon decay is not applicable to deep time and thus provides no insight into the age of the Earth. Second, and more importantly, dateable carbon is found exclusively in organic materials. As discussed below, life forms and their remains (fossils) can only be used to establish a relative geological time scale whereas the absolute time scale must be determined from igneous or metamorphic rocks. Emphasizing the use of ^{14}C dating can thus lead to fundamental confusions regarding the geologic time scale.

Understanding radiometric decay in a geological context can be facilitated by using relevant examples from rocks and minerals. We start by explaining that a radiometric age date records the amount of time that has passed since the sample cooled to a temperature at which solid state diffusion stops. This statement helps present geologic systems as dynamic and thermally-driven, both

key concepts for eventual comprehension of plate tectonic processes. From that perspective, the need for igneous and metamorphic rocks – both of which have been very warm – becomes clear. This recognition also provides an important segue into instruction about minerals: rather than memorizing suites of uncommon sample names, students can focus their learning on abundant and common minerals that provide key insights into the age of the Earth. The element potassium (root element for K-Ar dating) is abundant in K-feldspar, micas and amphiboles, while uranium (root element for U-Pb dating) is abundant in zircon and apatite. All of these minerals are common in granites and in many metamorphic rocks, as well as being readily available as student samples within an Earth Science classroom, and this approach helps students tie together the many threads of Earth science.

The geological time scale

The geological time scale is a beautiful example of interdisciplinary collaboration carried out by scientists over centuries and across continents. Fossil sequences provide clear relative time scales, but only where rocks of any particular age are exposed. The relative time scale based on fossil evidence thus captures research carried out on sedimentary sequences in quarries and road cuts on every continent. The geological eras and periods often take their names from key localities where this research was performed (Table 1). It is important to recognize that every named, geologic period records a fundamental global change in the fossil record, i.e., a mass extinction event related to profound environmental change of uncertain cause. Absolute ages as determined from igneous and metamorphic rocks are required to date these events in the geologic record, and also require the discovery and age determination of appropriate samples in key locations around the world.

Classroom time spent discussing the geological time scale provides important cross-curricular linkages. The time scale in Table 1 explains the period names in accessible language that is easily related to geographic and historical themes, promoting literacy engagement across science and the

CENOZOIC ERA (Age of Recent Life)	Quaternary Period	The geologic eras were originally named Primary, Secondary, Tertiary and Quaternary. The first two names are no longer used. Tertiary and Quaternary are now used as period designations.
	Tertiary Period	
MESOZOIC ERA (Age of Medieval Life)	Cretaceous Period	Derived from Latin word for chalk (creta) and first applied to extensive deposits that form white cliffs along the English Channel.
	Jurassic Period	Named for the Jura Mountains, located between France and Switzerland, where rocks of this age were first studied.
	Triassic Period	Taken from the word “trias” in recognition of the threefold character of these rocks in Europe.
PALEOZOIC ERA (Age of Ancient Life)	Permian Period	Named after the province of Perm, Russia, where these rocks were first studied.
	Pennsylvanian Period	Named for the state of Pennsylvania where these rocks have produced much coal.
	Mississippian Period	Named for the Mississippi River Valley where these rocks are well exposed.
	Devonian Period	Named after Devonshire, England, where these rocks were first studied.
	Silurian Period	Named after Celtic tribes, the Silures and the Ordovices, that lived in Wales during the Roman Conquest.
	Ordovician Period	
Cambrian Period	Taken from the Roman name for Wales (Cambria) where rocks containing the earliest evidence of complex forms of life were first studied.	
PRECAMBRIAN ERA		The time between the birth of the planet and the appearance of complex forms of life. More than 80% of the Earth’s estimated 4.55 billion years of history fall within this era.

<http://pubs.usgs.gov/gip/geotime/divisions.html>

humanities. Many good activities around the scale of geologic time help promote numeracy and the familiarity with large numbers that are the hallmarks of Earth science.

Conclusion

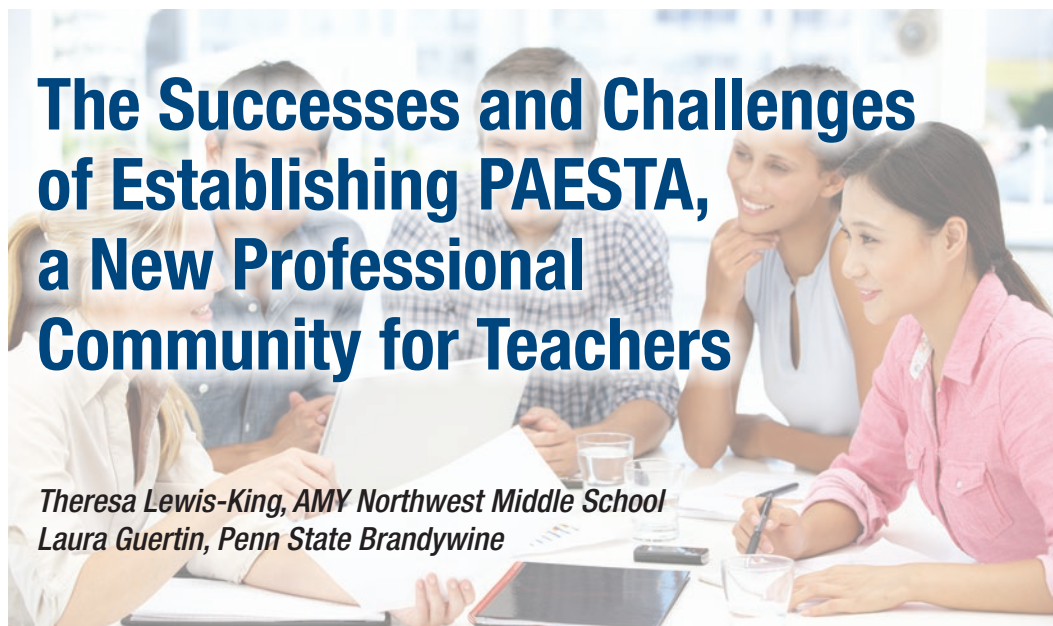
Teachers of Earth science typically face challenges in delivering a curriculum that is integrative and focused on building connections, rather than one which emphasizes memorization and lower-order thinking skills, because of the tremendous number of terms that are in everyday use in the field. This article provides a way to introduce a small suite of rock and mineral names within the context of understanding radiometric decay in a geological context as well as both absolute and relative geologic time. It also promotes discussion of the historical and geographic origins of the geological time scale, which enables further links to both literacy and numeracy that can be addressed within a self-contained classroom or with partner teachers in other disciplines. By using this approach, it is possible to introduce an understanding of the age of the Earth in light of the processes that formed our planet rather than asking students to accept an unimaginably large number as the indefensible truth. With this approach, the integrated nature of the science can be brought to bear in a welcoming environment where significant ideas and processes are discussed and made to connect with one another.

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About the Author

Tanya Furman is both a Professor of Geosciences and Assistant Vice President and Associate Dean for Undergraduate Education at Penn State University in University Park, PA. Her research focuses on the geochemistry of volcanoes in extensional environments and on teaching and learning in Earth Science classrooms at the university level. Dr. Furman can be reached at furman@psu.edu



The Successes and Challenges of Establishing PAESTA, a New Professional Community for Teachers

*Theresa Lewis-King, AMY Northwest Middle School
Laura Guertin, Penn State Brandywine*

Abstract

The Pennsylvania Earth Science Teachers Association (PAESTA) was established in 2011 as a professional community for Earth and Space science educators across Pennsylvania and beyond. The organization is led by an Executive Committee and a Teacher Advisory Committee that meet monthly to shape plans for the membership. PAESTA provides opportunities for networking through its annual conference and for member recognition through monthly, eNewsletter features, and a year-end teaching award. A supporting website provides access to existing resources and curricular materials provided by PAESTA members, as well as an advocacy page that speaks to national needs in the Earth and Space sciences. Although its initial growth has been successful, PAESTA faces the challenge of broadening the participation of teachers and increasing the resources available to the Earth and Space science community.

Introduction

The Pennsylvania Earth Science Teachers Association (PAESTA, Figure 1) was chartered in 2011 as a state chapter of the National Earth Science Teachers Association (NESTA). PAESTA was established with the purpose of promoting, improving and coordinating Earth and Space science education at all levels in the state of Pennsylvania. PAESTA membership is currently free and is open to all K-16 educators; however, our main audience comprises Pennsylvania K-12 classroom teachers, informal educators and pre-service teachers. The current membership also includes educators from five states outside of Pennsylvania.

The organization was conceived by two Pennsylvania State University faculty members, Tanya Furman (Geosciences, Penn State University Park) and Laura Guertin, (Earth Science, Penn State Brandywine) who understood the value and necessity of including in the initial development of a statewide organization, the voices of practicing K-12 teachers, especially those from the middle grades where Earth and Space science are taught in Pennsylvania. They were guided by accepted research on the role of teacher leadership in implementing and sustaining educational reform (e.g., Wynne, 2001) in addition to lessons they learned from their engagement with K-12 teacher professional development projects such as the Transforming Earth System Science Education (TESSE) program (Graham et al., 2007). PAESTA was established and continues to be funded



Figure 1. The logo of the Pennsylvania Earth Science Teachers Association (PAESTA).

from the Penn State Earth and Space Science Partnership (National Science Foundation Award #DUE-0962792).

The Teacher Advisory Committee

The PAESTA Executive Committee (President, President-Elect, Secretary/Treasurer and Past President), challenged with the mission of connecting Earth and Space science teachers throughout the entire state of Pennsylvania, conceived of the formation of a teacher advisory committee. The thought was that an active PAESTA Teacher Advisory Committee (TAC) could be instrumental in ensuring that PAESTA was responsive to the needs of the teachers it serves. The first meeting of TAC, composed of four experienced middle school teachers of Earth and Space science, took place in June 2012 at the Penn State Brandywine campus. They envisioned their primary role as creating opportunities for Pennsylvania Earth and Space science teachers to develop professional communities across curricular content, grade level and district/geographical boundaries.

Some early proposals from the TAC have proven valuable in advancing the growth of the organization, especially in showcasing teaching achievements. Based on TAC suggestions, PAESTA recognizes a Featured Member and monthly PAESTAR on its website and in its eNewsletter. The Featured Member highlights an individual teacher and the specific ESS content taught in that teacher's classroom. The featured teachers present "best" instructional practices in their own words and provide additional resources useful for teaching that specific content. This format provides an authentic context for teacher-to-teacher exchange of age appropriate Earth science lessons proven in the classroom. The TAC also felt strongly about the importance of recognizing and promoting ordinary teachers who often do the extraordinary work providing leadership and support for other teachers in their school buildings and districts. The PAESTAR, a monthly Pennsylvania Earth Science Teacher Achievement Recognition, shines a spotlight on a PAESTA member who has made a notable contribution to the Earth and space science community and/or has served as a leader in the discipline.

The PAESTA Executive Committee

The PAESTA Executive Committee relies on the TAC to help develop and sustain an organization relevant to and responsive to the needs of Pennsylvania educators and students. In many school districts throughout Pennsylvania, Earth science teachers work in isolation with minimal opportunities for professional collaboration with other teachers or Earth science professionals. There are a limited number of Earth science classes offered in Pennsylvania high schools, instead the emphasis is placed on physical and life science with Biology, Physics and Chemistry the predominate high school course offerings. Earth science is primarily taught in an integrated middle school science curriculum that covers life, physical, Earth and environmental science content. Pennsylvania middle school Earth science content includes: systems, models and patterns; Earth features and processes; weather, climate, and atmosphere; and the composition and structure of the universe. Improving Earth science instruction requires connecting professional geologists, research scientists, teachers and students. Professional geologists can provide teachers with current information about industry needs and help teachers prepare their students for possible careers in Earth science. Developing professional communities between academic researchers and classroom teachers helps develop Earth science educators equipped with the knowledge and skills necessary to teach rich, complicated science content using effective strategies that engage students.

The PAESTA Conference

The Executive Committee's desire to build bridges between professional geoscientists, the Penn State academic faculty, teachers and students sparked the creation of an annual conference.

PAESTA held its first conference October 12-13, 2012, at Penn State Brandywine in Media, PA, with 49 educators in attendance (Figure 2). The TAC provided valuable leadership in designing the conference format and ultimately presenting some of the dynamic teacher-led workshop sessions. The focus of this inaugural conference was on linking Earth and Space science instruction with career opportunities, which was coincident with the theme of the National Earth Science Week for 2012. The keynote speaker for the conference was Heather Houlton, Outreach Coordinator at the American Geosciences Institute (AGI) Workforce Program. She highlighted the importance of helping students explore the wide range of careers available in the geosciences, connecting the students' personal interests with current and future career opportunities in Earth science related fields. She gave conference participants a guided tour of the student-friendly resources available through the AGI Geosciences Career website (<https://www.agiweb.org/workforce>).

A collaborative model of developing Earth system science resources for the PAESTA community was used in the design of the conference. The TAC was enthusiastic about getting teachers to have productive conversations with each other during the conference sessions. One effective approach was to have conference participants working in small groups using a set of Pennsylvania State Standards from across disciplines to begin developing a structure for an online professional community. The online community will ultimately provide a place where all members can find instructional materials on Earth science topics, actively contribute to lesson planning resources, and find inspiration for their teaching. Incorporated in the conference schedule were several opportunities for participants to self-select small workshop sessions organized around topics directly related to their professional interests. Some of the classroom instruction related sessions included: Claims, Evidence, Reasoning (CER): Helping Students to Construct Scientific Explanations; The iPad as an Instructional Tool; A Cemetery as a Site for Multidisciplinary Teaching; and Introduction to Google Apps. There also were sessions focused on professional practices, educational research and specific Earth science content knowledge.

In addition to the conference sessions, the Executive Committee instituted the PAESTA Award for Teaching Excellence (separate from the regional NAGT Outstanding Earth Science Teacher Award) for the purpose of acknowledging a dedicated Pennsylvania K-12 educator who makes



Figure 2. Introduction to the PAESTA conference session, “Collaborative Approach to Developing Earth System Science Resources Through PAESTA.”

Photo by Laura Guertin.



Figure 3. Conference participants working in small groups during the PAESTA conference.

Photo by Laura Guertin.



Figure 4. Heather Spotts, winner of the 2012 PAESTA Award for Teaching Excellence.

Photo by Laura Guertin.

exemplary contributions to the field of Earth and Space science education. The 2012 PAESTA Award for Teaching Excellence was presented to Heather Spotts, a 6th grade, general science teacher from a rural district in Centre County, PA (Figure 4). Heather has worked hard to build strong partnerships with colleagues, thus laying the foundation for a thriving professional learning community in her district and beyond. For example, since its beginning, Heather has been a major partner in the Academic STEM Alliance which is composed of three rural school districts in central Pennsylvania. She remains actively involved because she is always seeking out opportunities for herself and her students to enrich their understanding of science.

From conference participant feedback, the PAESTA Executive Committee has realized the need to help teachers develop professional learning communities across curricular content, grade level and district/geographical boundaries. Although this is a legitimate organizational goal, there are clear challenges that include time constraints, insufficient content knowledge on the part of teachers, lack of high-quality material and instructional resources, and at times, lukewarm school district administrative support. All conference participants agreed that a collaborative approach was the most effective way to help develop and sustain PAESTA and its mission. Participants were extremely excited about the conference's Earth science career focus because it was thought practical to connect quality Earth science instruction to the prospect of increasing the number of students interested in the geosciences. Having up-to-date information about career options helps teachers design coursework that is relevant to existing Earth-related issues, encourages exploration and pursuit of careers in the geosciences, and helps them answer their students' question, "Why is Earth science important to study?"

Next Steps for PAESTA

Within a short period of time, PAESTA has established a foundation for growing and maintaining a vibrant statewide organization. In the spirit of collaboration, to avoid replicating resources that are currently available and for the purpose of sharing and exchanging information, PAESTA has begun an active outreach program. It has also begun to contact PA school districts, classroom teachers, state universities and colleges with active Earth science degree programs, and state and national science organizations such as the National Earth Science Teachers Association (NESTA), the National Science Teachers Association (NSTA), and the Pennsylvania Science Teachers Association (PSTA). The Executive Committee will be forming other committees as needed to help advance the mission of the organization.

The PAESTA website (<http://www.paesta.org/>) is established and yet is under continual development. The website is designed to be the principal vehicle for promoting professional community, disseminating information about Earth and Space science, and providing relevant information about current geological events. The website has recently been re-designed with teacher input to make it easier for teachers to navigate quickly and efficiently based on their instructional needs. The goal is to provide teachers and other community educators a central clearinghouse for accurate and reliable sources of information about Earth and Space science.

By its very nature and mission, PAESTA must confront the challenge of building professional community and maintaining connections among its members. This situation requires effective use of limited resources and funding available through the Penn State Earth and Space Science Partnership to provide Earth and Space science curricular materials that have proven benefits in strengthening instructional outcomes for students. PAESTA's success is dependent upon providing opportunities for K-12 teachers and community educators to communicate their needs, showcase their praxis, submit standards-based lesson activities, nominate themselves and colleagues for the various PAESTA recognitions, and serve as leaders in the organization. PAESTA is an example of an

active and developing organization that has established some important links among its members in Pennsylvania and beyond. Readers are invited to visit the PAESTA website and take advantage of the resources that are available to members and visitors. There have been some important lessons learned that could benefit others who might be considering the development of their own statewide chapter of an Earth science teachers organization, like PAESTA.

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About the Authors

Theresa Lewis-King is a middle school teacher at AMY Northwest Middle School in Philadelphia. Theresa can be reached at paestateacher@gmail.com

Laura Guertin is an Associate Professor of Earth Science at Penn State Brandywine, Media, PA. Her research involves studying how new and emerging technologies impact teaching and student learning in introductory-level Earth science courses at the university level. Dr. Guertin can be reached at guertin@psu.edu

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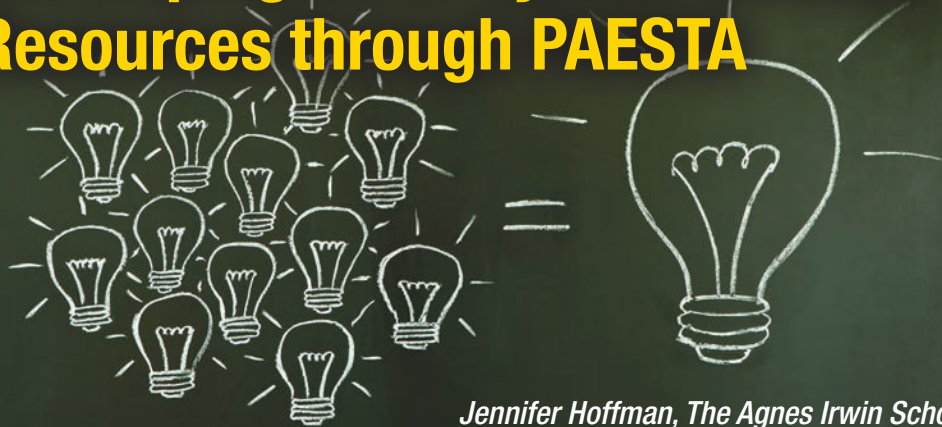
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A Collaborative Approach to Developing Earth System Science Resources through PAESTA



*Jennifer Hoffman, The Agnes Irwin School
Kelly Hunter, Snyder-Girotti Middle School*

Abstract

The Pennsylvania Earth Science Teachers Association (PAESTA) is a non-profit, educational organization committed to the advancement, extension, improvement and coordination of Earth Science education across all levels. It was created in 2011 as a state affiliate of the National Earth Science Teachers Association (NESTA). This article describes a workshop created by the Teacher Advisory Committee of PAESTA for the first annual PAESTA conference in October 2012 at the Brandywine campus of Penn State University. The goal of *A Collaborative Approach to Developing Earth System Science Resources Through PAESTA* was to facilitate partnership of K-12 teachers from across Pennsylvania in the construction of Pennsylvania standards based interdisciplinary units of study emphasizing current events and career opportunities related to Earth systems science. Via an initial conference session and continuing online discussion forums housed on the PAESTA website, the interdisciplinary units will continuously evolve. The organizers of the conference also sought to encourage greater participation in PAESTA and create a new paradigm for ongoing, personally directed professional development with emphasis on collegial support and interaction. It is hoped that this article can be used as a template for other states that wish to start their own state affiliate of NESTA.

Introduction

The first annual conference of the Pennsylvania Earth Science Teachers Association (PAESTA) was held October 12-13, 2012 at Penn State Brandywine in Media, PA. Roughly 50 science teachers and other science professionals from across Pennsylvania and surrounding states attended the conference. This article describes a conference session which aimed to create Pennsylvania standards based interdisciplinary units through collaborations of teachers across all grade levels. *A Collaborative Approach to Developing Earth System Science Resources Through PAESTA*, developed by the PAESTA Teacher Advisory Committee (including Lewis-King and Guertin, this issue) and facilitated by the authors. The goal of the workshop was to bring teachers together across distance and grade band with the shared mission of improving curricular resources around several key Earth and Space

science topics that are relevant to the Pennsylvania state standards as well as the Next Generation Science Standards soon to be implemented nationwide. The Teacher Advisory Committee also sought to introduce a dedicated web-based vehicle to continue the collaboration after the close of the meeting.

The Collaborative Approach

To facilitate the workshop, the committee created several templates for incipient online forums on the PAESTA website (<http://www.paesta.org/>) that emphasize topical current events and associated career options in the realm of Earth systems science. These several templates can be emulated by other ESTA organizations. The committee selected seven topics for the online communities: (1) Earthquakes as natural disasters; (2) Hurricanes as natural disasters; (3) Natural gas extraction in Pennsylvania; (4) Solar system exploration – do moons support life?; (5) Theory of plate tectonics; (6) Water cycle; and (7) Weather patterns. Conference attendees were given the opportunity at the onset of the workshop to select the topic that resonated most with their personal or professional interest. Teams were given time for introductions and then were presented with the template for their topical area – a selection of statements from several Pennsylvania and Common Core standards – to act as an initial focus for discussion and collaboration within the team (see Table 1). Standards chosen to frame the units on Natural gas extraction in Pennsylvania and Hurricanes as natural disasters, as well as the other topics, can be found in the Collaborative Approach discussion boards on the PAESTA website (<http://www.paesta.psu.edu/forums/collaborative-approach>). Teacher Advisory Committee members viewed the templates as a starting point for collaboration, acknowledging that the team may add to or subtract from the standard statements over time.

Instruction for each of the topics chosen by the Teacher Advisory Committee could be conducted as a stand-alone science unit or as part of a larger interdisciplinary unit across several disciplines. For example, a unit “Natural gas extraction in Pennsylvania” could be integrated with a variety of other subjects including, but not limited to, history, economics, English composition or language arts, Earth science, chemistry and environmental science. From a historical perspective, the unit could include a history of natural gas extraction in Pennsylvania, a history of the extraction of other natural resources in Pennsylvania, the role of the government and special interest groups in natural gas extraction, or a look at the societal impacts of the process. An economics class could conduct cost/benefit analyses of natural gas extraction in Pennsylvania and other states, as well as a cost comparison between natural gas and coal. Any language arts class could conduct research on the topic followed by a debate, presentation, or written assignment. Most standardized testing focuses on non-fiction reading comprehension and the language arts classes could also read essays on natural gas extraction for analysis. Earth science was the original focus for the unit; however, it could also be expanded within a chemistry or environmental science class as well.

A “Hurricanes as a natural disaster” unit could also be designed with an interdisciplinary approach by including the following disciplines: geography, algebra, economics, history, language arts, Earth science and environmental science. Within a geography class, the unit could examine the effects that physical processes have on an area’s topography and how the topography changes over time

Question: The natural gas industry is booming in Pennsylvania. Why is natural gas under Pennsylvania and what regions of the state have this natural resource? What job opportunities exist in the natural gas industry and what education or training is required? What are the impacts of the natural gas industry on the environment and how can technology play a role in protecting the environment?

Question: Hurricanes are a common natural disaster that affects the Eastern and Southern Coasts of the US. With the destruction caused by massive hurricanes, like Hurricane Katrina, scientists are constantly exploring conditions that cause hurricanes. What are the conditions that create Hurricanes? What preparations can be done to help eliminate hurricane damage? What type of scientists work on hurricane predictions, preparations, and after effects? What technologies are used to study hurricanes?

Table 1. Framing Questions for Group Discussions on Natural Gas Extraction in Pennsylvania, and Hurricanes as a Natural Disaster.

because of these processes. An algebra class could compute equations determining the speed of the hurricane or the distance it would travel, as well as, track and predict the path of the hurricane. Economics classes could determine costs for preparation, clean-up, and support and the effects these costs would have on local, state, and national governments. Since the United States has such an extensive history of hurricanes, history classes could examine past major hurricanes and their effects on the impacted area. Finally, language arts classes could analyze newspaper articles about past hurricanes or write essays from an emotional standpoint about what would happen if they lost everything in a hurricane or a scenario where they did not evacuate and lived through the hurricane.

During the workshop, each team brainstormed for about 45 minutes while reflecting on the template of standard statements. Note-takers were assigned within each group to capture the brainstorming as the first entries for each online discussion forum on the PAESTA website. Participants were encouraged to continue submitting information, questions and resources to the discussion. As the communities worked on the unit development, members of the PAESTA Teacher Advisory Committee moved among the teams to answer questions, suggest ideas and facilitate discussions.

As the communities worked, open communication and mutual respect among the group members was essential. All members played an active role in the development of the communities which led to a diverse range of ideas. This diversity created great discussions in the groups and a variety of ideas for the unit that would be beneficial to composing material accessible to teachers from any district, regardless of their school's structure. Suggestions were presented for activities across many spectrums: urban to rural settings, low-budget to high-budget activities, elementary to post-secondary levels, minimal technology access to maximal technology access, private school settings to public school settings. The communities embraced all of the different backgrounds and worked to find ways to meet the needs of all its constituents.

Outcomes

The PAESTA Teacher Advisory Committee identified as the primary product of this workshop the creation of several online discussion forums housed on the PAESTA website. These forums were conceived as a model of ongoing professional development that could serve to enhance teacher access to content resources, pedagogical strategies, interdisciplinary collaboration and career options related to specific topics in earth systems science. Online forums also serve to connect science teachers across the region, encouraging dissemination of information and resources. Additionally, the Committee hopes to encourage greater participation in PAESTA as participants continue to visit the PAESTA website to access their online forums. The workshop united teachers from various backgrounds into interactive communities that can continue into the future. This structured activity allowed teachers a chance to have a voice and to develop a product, as well as to build new professional relationships. Post-conference surveys indicated that participants valued the opportunity to work collaboratively in this setting. The hope is to continue to build these professional communities within PAESTA to achieve this purpose while also creating comprehensive units as a resource for the membership.

Conclusion

Ultimately, it is the hope of the PAESTA Teacher Advisory Committee, that the discussion forums function as springboards, for teacher-developed units of study that include non-fiction readings, teacher-vetted classroom activities, current events, and information on careers in the earth sciences. It is imperative that teachers prepare students for the highly technical careers of the 21st century, and the increased demand for earth science professionals to design solutions to pressing, local

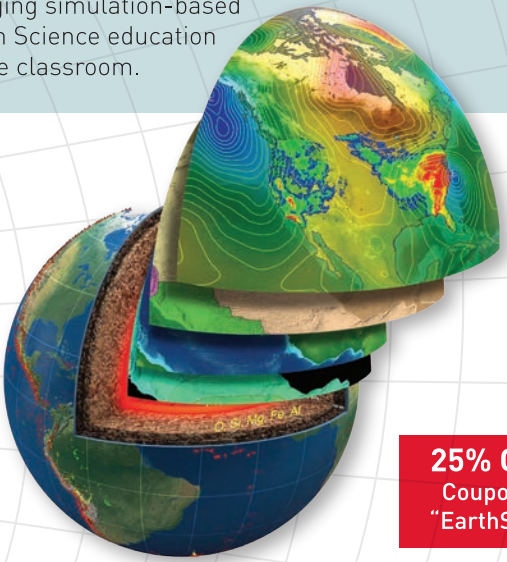
and global environmental problems, such as global warming, agricultural productivity, and the appropriate development of renewable and non-renewable energy resources. As many high-stakes standardized tests focus on non-fiction literature, one goal was to highlight sample readings that can be used within science units to foster reading fluency and comprehension. It is the perception of many earth science teachers, that students need more support connecting science learning in the classroom to current events and potential careers available to them. By facilitating greater access to contextualized information on current events and careers in units of study, the PAESTA Teacher Advisory Committee hopes the online communities developing on the PAESTA website, evolve to become important resources for teachers in states across the continent.

About the Authors

Kelly Hunter is an Earth and Space Science Teacher and Department Chair at Snyder-Girotti Middle School, in Bristol, PA. She is also the President-Elec for, and on the Teacher Advisory Committee of PAESTA. Kelly can be reached at kelcole3@gmail.com

Jennifer Hoffman is an Earth and Space Science Teacher, AP Environmental Science Teacher and Department Chair at the Agnes Irwin School, in Rosemont, PA. She is a member of the Teacher Advisory Committee for PAESTA. Jennifer can be reached at jhoffman@agnesirwin.org

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Student Conceptions of the Cause and Locations of Earthquakes

*Peter Licona, Penn State University
Scott McDonald, Penn State University
Tanya Furman, Penn State University
Laura Guertin, Penn State Brandywine*

Abstract

While many students are familiar with the geological phenomenon of earthquakes, still other students hold alternative conceptions about the causes and/or locations of earthquakes. For this study, assessments were administered to students ($n = 359$) ranging in age from elementary to high school level. Student responses were categorized as correct or incorrect based on inclusion of key terminology related to plate tectonics. Our results confirm that many students across grade levels hold alternative conceptions related to the causes and locations of earthquakes. This research has pedagogical and curricular implications for improving geoscience education.

Introduction

Students of all levels have some knowledge of the phenomenon of earthquakes. Students are exposed to media reports of earthquakes throughout the world as well as “reports” in television shows and Hollywood films. While many students are familiar with earthquakes and the damage they cause, they often do not fully understand the causes nor locations of earthquakes. Understanding the nature of commonly-held alternative conceptions can help teachers support students as they reach a better understanding of how, where and why earthquakes occur.

Alternative Conceptions

Alternative conceptions (Clark, et. al., 2011), sometimes referred to as misconceptions (Francek, 2013), are those student-held ideas about scientific phenomena that deviate from the normative, scientifically accepted explanations. Students’ alternative conceptions often persist even after instruction around the normative scientific concepts. The origins of alternative conceptions are as varied as the conceptions themselves. Alternative conceptions can come from formal and informal educational settings, movies and television, the news media, folk stories, legends, as well as idiosyncratic ideas students develop on their own, related to a given phenomenon (Smith & Bermea 2012).

Previous Studies of Student Conceptions of Earthquakes

Research into student conceptions of the causes and locations earthquake is sparse but does show that many students have difficulties expressing scientifically accurate conceptions of the causes and locations of earthquakes. Tsai (2001) researched Taiwanese student conceptions about the causes

of earthquakes shortly following a destructive earthquake in Taiwan. He found that students' personal beliefs or their worldviews, which included the supernatural, myths, and scientific misconceptions, were what actually formed their conceptions about the causes of earthquakes. In his research, student responses that could be classified as scientifically accurate comprised only 27% of all responses.

Ross and Shuell (1993) interviewed American students in grades K-6 about their understanding of earthquakes. They noted that students had difficulty explaining the causes of earthquakes and many responded to interview questions that they did not know what causes earthquakes. A small percentage of students (~8%) responded that volcanoes cause earthquakes, and some students described earthquakes as producing weather-like conditions such as high winds and tornadoes. At the college level, Libarkin et al. (2005) analyzed 235 student responses to open-ended questionnaires and interviews on various Earth science topics. On a question related to the causes of earthquakes, 11% of students replied that the causes were: people/animals, temperature/heat, gravity, air pockets/gas pressure, weather/climate, and lava/volcanoes.

This article presents findings from preliminary research on student conceptions of the causes and locations of earthquakes, focusing on two research questions: (1) What are student conceptions about the causes of earthquakes? (2) What are student conceptions about the locations and pattern of locations of earthquakes?

Methods

This research is part of The Pennsylvania State University's Targeted Math Science Partnership (NSF-MSP) grant that is collaborating with several Pennsylvania public school districts. In order to investigate Pennsylvania middle school students' conceptions of earthquakes, the project developed a written assessment containing various questions ranging from the break-up of Pangaea, to the interior structure of Earth.

During the spring of 2011, assessments were collected from 359 students in grades 4-12, from eleven schools representing four large, urban school districts and one suburban school district. These students were not necessarily enrolled in earth science or a science course that had an earth science focus, as the research was not attempting to link instruction and students conceptions. Within the overall assessment, students were prompted to answer two questions related to earthquakes:

1. There have been several recent earthquakes in different parts of the world. For example, there were three very big earthquakes in Chile, Haiti and Japan that each caused a lot of damage. Please explain what causes earthquakes.
2. Why do earthquakes occur most often in certain parts of the world?

Assessments were analyzed, based on the terminology students used to explain the causes and locations of earthquakes. Responses were classified as correct or incorrect based on the inclusion or omission of terminology related to plate tectonics, faults, or release of energy (Libarkin et al., 2005). Responses to question one were initially grouped into three main categories: answers mentioning plate tectonics, faults, or the release of energy; those that do not; and no response (which included irrelevant responses and "I don't know"). Responses that mentioned plate tectonics, faults, or the release of energy were categorized as "correct". Those responses not mentioning them were categorized as alternative conceptions. As the research team was not going to be able to conduct follow-up interviews, the responses to question two were used to probe for deeper understandings of earthquakes.

Results

Of 359 student responses, 216 of the 359 student responses (60%) were coded as correct. Fifty-six students (16%) either left the answer blank, responded with “I don’t know”, or responded with an irrelevant response. The remaining 87 of the 359 student responses (24%) were coded as alternative conceptions. The largest category among alternative conceptions (see Figure 1) consisted of answers that described movements of land, earth, or dirt but without explicit mention of tectonic plates. Examples include: “land rumbled and cracked”, “crack in the ground” and “earth moves”. The second largest category among the alternative conceptions consisted of responses that described the action of or presence of water. Examples included: “the land is moving because water is pushing it”, “what causes earthquakes are sea or ocean”, “the ground shaking from too much water” and simply “water”. A few students mentioned volcanoes as the cause of earthquakes, which could indicate awareness of tremors associated with ascending magma but within the context of these students’ full suite of answers they appeared to represent alternative conceptions. Other factors categorized as alternative conceptions include climate and heat.

Figure 1. Percentages of student alternative conceptions for causes of earthquakes

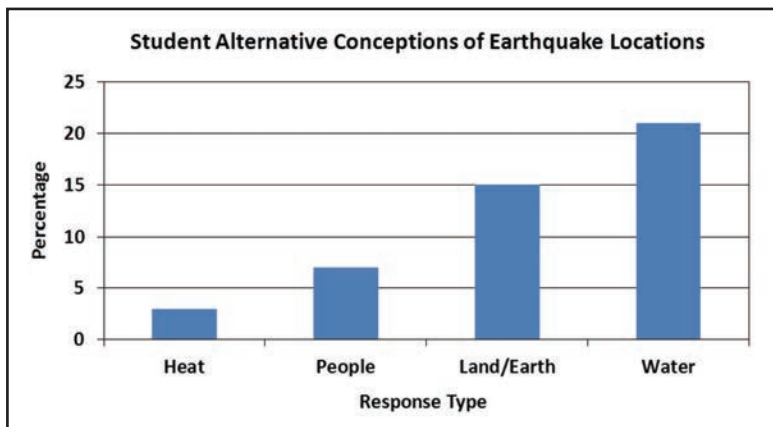
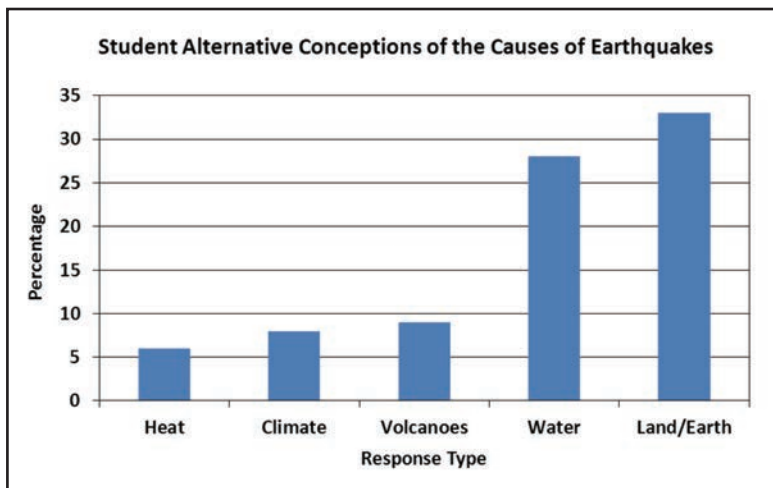


Figure 2. Percentage of student alternative conceptions for locations of earthquakes

In reference to the *location* of earthquakes, 148 of the 359 student responses (41%) mentioned plates, plate boundaries or faults. There were 67 of the 359 students (19%) who left the answer blank or responded with “I don’t know”. The remaining 144 of the 359 student responses (40%) responses were considered alternative conceptions, the most common of which are represented in Figure 2. The largest category among the alternative conceptions consisted of responses in which water or oceans were included. Examples included: “because it’s near water or ocean”, “because they have big oceans”, and “certain parts of the world live near the ocean which may get earthquakes”. The second largest category was titled land/Earth and included responses such as, “there is high and low land”, “earth moves, and “more land”. A few students mentioned volcanoes as the cause of earthquakes, which could indicate awareness of tremors associated with ascending magma but within the context of these students’ full suite of answers they appeared to represent alternative conceptions. Other factors mentioned as alternative conceptions include people and heat.

quakes, which could indicate awareness of tremors associated with ascending magma but within the context of these students’ full suite of answers they appeared to represent alternative conceptions. Other factors mentioned as alternative conceptions include people and heat.

Discussion

The results provide insight into some common conceptions that students have regarding both the causes and locations of earthquakes. Too many students across all grade bands demonstrate alternative conceptions or are able to articulate no conception at all. This result raises some concerns regarding instruction related to the causes and locations of earthquakes.

It is important to consider how these alternative conceptions may have arisen. Most of the responses categorized as land/earth described the *effects* of an earthquake rather than the *cause*. This

type of conception indicates that teachers need to support students when differentiating between the cause of a geologic phenomenon and its effects. The responses that relate to water, both in terms of causality and location, might be explained in light of the recent earthquake in Japan, which resulted in a devastating tsunami. It is important for teachers to help students understand the information presented in the media and ensure they develop scientifically-appropriate understandings of the relationships between earthquakes and water, including tsunamis which can result from, but not cause, an earthquake. For example, teachers can present data showing earthquake locations distributed across the globe, helping students see that earthquakes occur far from bodies of water, as well as near.

While the explanations for these alternative frameworks need to be explored and addressed through appropriate instruction, it is important also, to shed more light on responses categorized as “correct”. Mentioning plate tectonics, faults, or release of energy does not communicate full understanding of the causes and/or locations of earthquakes. Many of the student responses could be considered “incomplete”, or offer only a partial scientific explanation. Stating “plate tectonics” as a cause of earthquakes, or “plate boundaries” as the location of earthquakes does little to demonstrate that students have a rich conceptual understanding. These answers do indicate that a student is at least familiar with terminology and its usage. Teachers must consider both these “correct” conceptions and students’ “alternative conceptions” as building blocks in order to help students achieve a more scientific understanding of a given geologic phenomenon. For example, a student response that states that earthquakes occur at plate boundaries can be considered a building block towards a deeper and more sophisticated understanding of earthquake patterns.

Implications of Study

The quantity and diversity of student alternative conceptions indicate the importance of assessing students’ prior knowledge as a regular part of regular instruction. As these alternative conceptions are brought to light, teachers should plan instructional strategies that can be used effectively to target these alternative conceptions. Written assessments of prior knowledge (Hein, 1999) with classroom discussion can be an effective way of revealing student conceptions (Furtak and Ruiz-Primo, 2008). Conceptual change literature (Posner et al, 1982) can be helpful in assisting teachers conceptualize the process of changing an alternative framework to a more scientific explanation. Classroom activities should be selected to provide students with the opportunity to address their own conceptions and build on them, while moving toward more normative understandings. One example the authors recommend is the Discovering Plate Boundaries activity developed by Sawyer et al. (2005). This activity is useful because it has students use data to investigate the locations of earthquakes across the globe, thus allowing them to confront their own prior conceptions of the locations of earthquakes, and also connect earthquakes to other, key Earth science phenomenon, such as volcanoes and plate boundaries.

This research indicates that many students clearly hold a suite of alternative conceptions about the causes and locations of earthquakes. The implications are directly related to curriculum and instruction of this geoscience topic. It is important that teachers are aware of students’ alternative conceptions, but more important is that teachers are able to use student conceptions in preparing appropriate earth science lessons. Even though these results were based on assessing students in a wide range of grades, it is unrealistic to assume that these findings are generalizable to the entire population of students in the nation’s schools. What the results do provide is knowledge of the range of alternative conceptions which can then be used to plan effective instruction. Further research includes the recognition of patterns of conceptions within and across grade bands as well as instruction that targets alternative conceptions.

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About the Authors

Peter R. Licon is a doctoral candidate in Science Education at The Pennsylvania State University. In addition to his doctoral studies, he is a research and teaching assistant. He was a science teacher for 15 years before returning to pursue a Ph.D. His research interests include curricular and pedagogical strategies to enhance ethnic and linguistic minority groups' access to science. Peter can be reached at prl5046@psu.edu

Dr. Scott McDonald is an Associate Professor of Science Education at The Pennsylvania State University. He was high school Physics teacher prior to earning his Ph.D. in Science Education from the University of Michigan. He is Co-PI of the National Science Foundation funded Earth and Space Science Partnership (<http://www.essp.psu.edu/>) with research focusing on learning progression in Plate Tectonics and Astronomy. Dr. McDonald can be reached at smcdonald@psu.edu

Tanya Furman is both a Professor of Geosciences and Assistant Vice President and Associate Dean for Undergraduate Education at Penn State University in University Park, PA. Her research focuses on the geochemistry of volcanoes in extensional environments and on teaching and learning in Earth Science classrooms at the university level. Dr. Furman can be reached at furman@psu.edu

Laura Guertin is an Associate Professor of Earth Science at Penn State Brandywine, Media, PA. Her research involves studying how new and emerging technologies impact teaching and student learning in introductory-level Earth science courses at the university level. Dr. Guertin can be reached at guertin@psu.edu



Student and Teacher Conceptions of the Earth's Interior Structure

*Megan Pickard, Department of Geosciences, Pennsylvania State University,
Laura Guertin, Division of Earth Science, Penn State Brandywine
Tanya Furman, Department of Geosciences, Pennsylvania State University*

Abstract

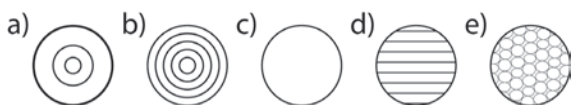
This investigation explores student and teacher conceptions of the interior of the Earth in upper elementary through high school grades in Pennsylvania. Student and teacher responses to two questions related to the structure of Earth's interior reveal several common themes: misuse of terminology, incomplete conceptions, naïve conceptions, and learned conceptions. Teacher responses were overall more sophisticated than those of the students but indicate incomplete conceptions and confusion of physical versus chemical layers of Earth's interior. Understanding the implications of the Earth's interior requires knowledge of complex Earth processes. Popular instructional methods based on memorization of the layered planetary interior do not lead to an understanding of those processes. Instead early instruction should focus on easy to understand locations and patterns of observable phenomena. These process-rich patterns set a foundation that can later be built upon when teaching the Earth's interior as the students progress in their knowledge of Earth processes.

Introduction

Most K-12 Earth science units include stand-alone sections on rocks, minerals, volcanoes and earthquakes. Rich comprehension of these topics, however, requires understanding their interrelationships in a tectonic context. One ubiquitous example is the interior of the Earth, specifically, the identification of crust, mantle and core which in turn has implications that are profound to understanding the formation of the Earth, heat flow within and out of the Earth and plate tectonic processes. Unfortunately, this content is rarely presented in a way that promotes a connection to these processes. Instead, nearly every textbook provides an illustration of a cut-away model of the Earth from which students memorize the terms: crust, mantle, and core, and hopefully apply those terms correctly to the model. The meaning and implications of the interior of the Earth are typically lost in this method of teaching.

In previous studies, both students and teachers demonstrated an incorrect understanding of the concepts of the Earth's interior, such as viewing Earth's interior as concentric spherical layers or flat layers (not spherical), being unable to correctly identify individual layers in the Earth or draw them to scale (e.g. Lillo 1994; DeLaughter et al. 1998; King 2000; Libarkin et al. 2005; Steer et al. 2005). Steer et al. (2005) found that even undergraduate students had only a rudimentary understanding

Figure 1. The first question about the Earth's interior from a survey for 4-12 grade students and teachers asked the participants to choose which of five illustrations they believed to be the most correct depiction of the interior of Earth.



of the interior of the Earth, and King (2000) noted that almost half the teachers studied struggled with the concept of scale in the Earth's interior, particularly the size of the crust relative to the rest of Earth. These findings suggest that popular methods of teaching the interior of the Earth do not yield even a basic understanding.

In the summer of 2010, the Earth and Space Science Partnership of Penn State University provided teacher professional development workshops for middle and high school teachers. In order to gain insight into student and teacher levels of understanding, we asked 17 teachers and 361 of their students

to answer survey questions about Earth science. The survey included a subset of questions from the Geoscience Concept Inventory (Libarkin & Anderson, 2005) to help us identify key concepts for targeted instruction in our summer workshop. Two questions were written specifically to probe student and teacher understanding of the Earth's interior. The first

question, "Which picture best represents the interior of the Earth", asked the participants to choose which of five illustrations they believed to be the most correct depiction of the interior of Earth (see Figure 1). Multiple choice answer options were based on previous studies of the Earth's interior, with option "a", layers drawn to scale, as the normative choice. The second question, "Describe the interior of the Earth based on the picture you picked", asked participants to describe the interior

of the Earth based on the illustration they chose. The participants' answers to those questions indicate that the majority of students had only a rudimentary understanding of Earth's interior and while teachers exhibited a greater understanding, they still struggled to make connections with other Earth processes.

Student Understanding

Student multiple choice results (see Figure 2) show that while the percentage choosing the normative answer increases with grade, many wrong answers were also chosen by the older students. Interestingly, 4th grade students who had not yet received instruction in school showed the smallest distribution of answers. Student written responses indicated widespread knowledge of some terms relating to the Earth's interior, but very few students attempted to describe the

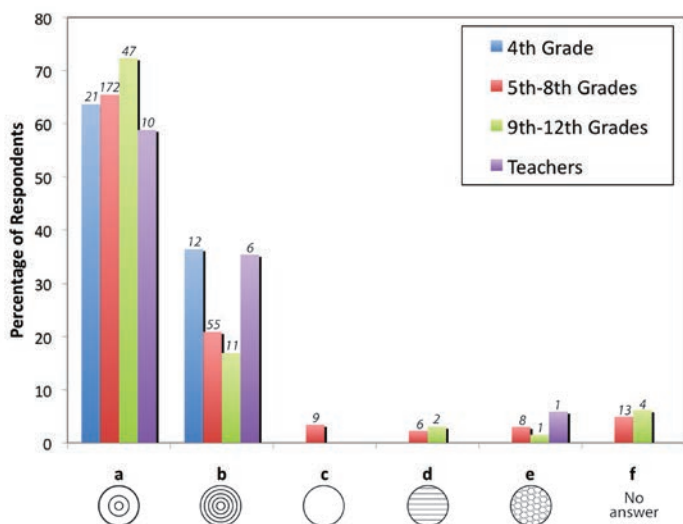


Figure 2. Student and teacher responses are shown as the percentage of respondents who picked individual answers. Students are grouped as elementary grades (4th grade), middle grades (5th-8th grades) or upper grades (9th-12th grades). The number of respondents who selected an answer is given above each bar.

interior using either physical or chemical characteristics. Two students wrote the following as their description of the interior of the Earth:

"There are different layers, each made of something different." – 11/12th Grade

"Different layers consist of different temperatures and materials or rock." – 7th Grade

While many students picked the correct image and/or identified crust, mantle, outer core, inner core, their answers to process-oriented survey questions indicated no conceptual link between the interior of the Earth and plate tectonics. For example when asked to explain how lava and magma form and where they come from one student wrote:

"[Lava/magma] come from the core." – 8th Grade

Several students appealed to supernatural processes or actors. For example, in response to a question about the causes of earthquakes one student wrote:

"Mother nature drops bombs anywhere she wants to." – 11/12th Grade

We identified four common themes among the student written responses. First is a misuse of terminology, represented by students who list some or all of the appropriate terms as well as those who include lava or magma as layers in the Earth.

“surface, mantle, inner mantle, core” – 5th Grade

“crust, inter crust, magma, outer crust” – 8th Grade

Second, we find students with incomplete conceptions about the interior of the Earth. Students in this category could list and label or describe the location of layers, or who gave blank statements about different, multiple, or many layers.

“Earth has different layers” – 11/12th Grade

The third theme is that of naïve conceptions where students attempt to describe the interior of the Earth by making non-normative connections to objects with which they are familiar. Some of the more common terms used, include: rock, dirt, water, sky, soil, ozone, and coal.

The fourth theme is one of learned conceptions. Some students responded that they had seen pictures of the Earth’s interior that helped them choose an illustration.

“[Saw] this picture on TV and in the movie 2012” – 6th Grade

Student responses in this group also used terms that came from pictures they saw or examples used in attempt to help them visualize the interior of the Earth, such as references to jawbreakers and archery targets or describing the layers as different colors such as orange, red or *“the yellow glowy thing”* (5th Grade).

Teacher Understanding

When compared to the students, the middle grade teachers exhibited a more sophisticated understanding of the interior of the Earth, both in choosing the most correct illustration, and in their written descriptions (see Figure 2). They typically had knowledge of appropriate terms and most worked to describe the interior in terms of both physical and chemical characteristics.

“A thin crust (thick outer line) underlain by a very thick mantle. These two layers are rock. The two interior layers are iron/nickel, with the outer of the two liquid and the core layer being solid”

A few teachers also indicated in their answers an understanding of processes connected with the interior of the Earth.

“...Outer core – liquid material that rotates around the solid Fe inner core, generating Earth’s magnetic field and the heat convected out is driving force behind convection currents.”

We identified only two of the four student themes in the written responses given by the teachers: misuse of terminology and incomplete conceptions.

“There is a hard core surrounded by magma that is surrounded by a mantle.”

“The Earth [has] 3 major layers that can be divided into smaller layers based on their composition”

In many cases, the teacher responses revealed confusion between layers distinguished by their composition (crust – mantle – core) and those distinguished by their thermal state (lithosphere – asthenosphere).

“The inner earth has layers of crust, mantle, core. The lithosphere is a layer (not really positive about placement).”

“Inner core, outer core, mantle, asthenosphere, lithosphere, crust”

None of the teachers referred to instructional images, proxies or visualizations. At the same time, the teachers did not provide evidence of deep understanding that would enable them to help their students work through their own alternative conceptions of Earth's interior or to relate the planetary structure to the process of plate tectonics.

Implications

The survey results indicate substantial overlap between student and teacher conceptions of the interior of the Earth. Most students and teachers can identify the correct picture of the interior of the Earth and provide some appropriate terms as labels. Overall, however, there is a lack of understanding that goes beyond the labels and that allows seeing contextualized implications of the interior of the Earth and its relationship to plate tectonics and Earth processes. Prior to attending the professional development workshop, teachers were asked to self-assess their *knowledge* of plate tectonics as well as their *ability to teach* plate tectonics. The majority of teachers reported their understanding of plate tectonics processes and features as moderate (2.96 on scale of 1-5) and felt moderately comfortable teaching the subject (2.92 on scale of 1-5). Reflecting on the answers provided by students and teachers about the interior of the Earth in this context indicates that the teaching of plate tectonics often employs only lower-order thinking skills such as memorization (e.g., name the layers of the Earth) which does not lead to an understanding of process knowledge. In a post-workshop survey these same teachers reported a higher level of both understanding (3.96) and comfort teaching plate tectonics (4.10). While acknowledging the potential challenge of interpreting data on small sample sizes (17 teachers), these results are heartening (Mundry et al. 2013).

Facility with nomenclature need not be a barrier to new understanding and this study suggests that the inability to name layers would indeed not present a barrier to understanding Earth processes. Early instruction should omit memorization of layers in the interior of the Earth as it contributes little, if anything, to the understanding of the important and complex themes of Earth science. Instead, focus should be on concepts that connect geologic phenomena with students' lives and experiences. Therefore, early instruction should focus on the location and pattern of observable phenomena that lead towards a basic understanding of plate tectonics and other Earth processes. These patterns are visual and ultimately process-rich. These patterns are ones that young children can comprehend and that form a basic foundation on which to build more complex knowledge about the Earth processes, including the interior of the Earth.

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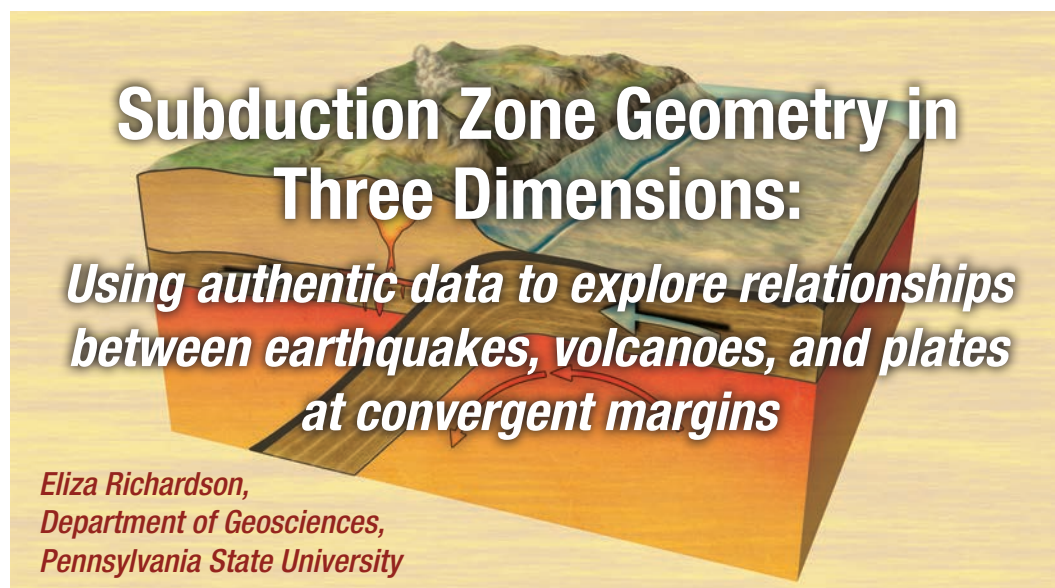
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About the Authors

Megan Pickard is a doctoral candidate in Geosciences at The Pennsylvania State University. In the fall of 2013, she will be starting a faculty position in the Geology Department at Brigham Young University – Idaho. Currently, Megan can be reached at mup163@psu.edu

Laura Guertin is an Associate Professor of Earth Science at Penn State Brandywine, Media, PA. Her research involves studying how new and emerging technologies impact teaching and student learning in introductory-level Earth science courses at the university level. Dr. Guertin can be reached at guertin@psu.edu

Tanya Furman is a Professor of Geosciences and Assistant Vice President and Associate Dean for Undergraduate Education at The Pennsylvania State University, University Park, PA. Tanya can be reached at furman@psu.edu



Abstract

The ability to visualize features of the Earth in three-dimensional space, and to conceptualize how these features change over long time scales, are crucial skills for geoscientists, but are skills that are arguably under-emphasized at the K-12 level (Kastens et al., 2010). The exercise presented here is specifically designed to build geometrical visualization skills while exposing students to authentic real-time data. This exercise was first developed and presented at the 2012 Plate Tectonics workshop at Penn State University as part of an NSF Targeted Math Science Partnership grant for Middle Grades Earth and Space Science Education (Award #DUE-0962792 & Award #GEO-0631377). All materials for teaching this activity including instructions and map templates are available for download at <http://www.paesta.psu.edu/classroom/subduction-zone-geometry>.

Introduction

K-12 students have little hope of internalizing big picture ideas about the Earth if they have an inadequate mental model of how those ideas are manifest in space and time. This exercise addresses this challenge by giving students the opportunity to construct their own graphs of spatial data using openly available authentic sources. The data in this exercise consist of earthquake and volcano locations at a variety of subduction zones around the world. At subduction zones, or convergent margins, two plates collide and one plate is forced under the other. Oceanic crust is recycled at subduction zones as it is forced into the mantle where it may descend as far down as the core-mantle boundary. Subduction processes form many spectacular features of our planet including deep ocean trenches and the volcanoes that form the Pacific Ring of Fire. Convergent plate boundaries are also where the planet's largest earthquakes and the great majority of tsunami-producing earthquakes occur. Visualizing the three-dimensional geometry of subduction zones is a logical step in the progression students make towards developing a conceptual mechanical understanding of the theory of plate tectonics.

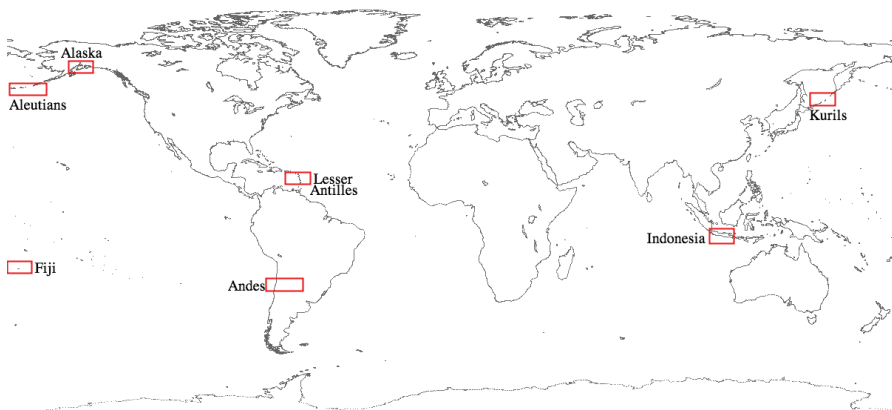
Learning Objectives

The objectives of this exercise are to use authentic data to discover (1) how earthquake locations define the shape of the downgoing plate at a convergent margin and (2) how the distance between arc volcanoes and the trench allows scientists to infer the angle of subduction. Most students are

accustomed to seeing maps on which earthquake locations have been projected onto the Earth's surface, but in this activity students will also explore the subduction process using graphs that allow the depth of earthquakes to be displayed. Because earthquakes occur within and along the top of the subducting plate, these earthquake locations tell scientists where the slab is located. Indeed, mapping of earthquake locations was a critical step in early research documenting the subduction process (e.g. Isacks et al., 1968). Once the locations of subduction zone arc volcanoes are added to the map, students can observe the spatial relationships between the trench, the over-riding plate and the subducting plate. This exercise demonstrates how scientists combine evidence from a variety of observations to develop a big idea and it can serve as an introduction to more in-depth lessons concerning descriptions of the mechanics of earthquakes and volcanoes. Although designed for upper middle grades, this activity can be used in upper elementary classrooms or for differentiated instruction by changing the amount and nature of the information given to the students.

A third objective of this activity is to enhance students' spatial thinking abilities. The inability of many students to think critically in the spatial realm has been identified by researchers in geoscience education (e.g. Kastens et al., 2009; Kastens, 2010) and is also the focus of more general endeavors to study human "sense-making" abilities (Lee and Bednarz, 2012 and references therein). Furthermore, the ability of students to develop an adequate mental model of complicated and dynamic Earth systems has been shown to depend on their prior knowledge of the system (Sell et al., 2006). This exercise is designed to build a simple foundation of accurate spatial thinking about subduction zones with the hope that students will be able to add to their model as their learning progresses in later years to include such complex topics as arc volcanism and mantle convection. This exercise also incorporates important Earth-science-related skills such as map reading, converting distance to map scale, and basic plot-making.

Figure 1. World map. Red boxes indicate portions of subduction zones used in this activity. For detailed instructions on how to extend this activity to other subduction zones besides the southern Andes example detailed in this article, go to <http://www.paesta.psu.edu/classroom/subduction-zone-geometry>.



The Activity

The following is a detailed description of how this activity works for the Southern Andes subduction zone, but this activity can be extended as a jigsaw activity to include other subduction zones indicated on Figure 1 (details and maps for additional locations including the Lesser Antilles, Indonesia, Kuril Islands, Southern Alaska, Aleutian Islands and Fiji Islands are at <http://www.paesta.psu.edu/classroom/subduction-zone-geometry>).

Prior to working on this exercise, students need to know that the scientists locate where earthquakes happen using the coordinates latitude, longitude, and depth. Students will also need to have some familiarity with plotting (x,y) pairs of points on a Cartesian grid. The grids on which the students make plots are given to them as part of the exercise materials, but they will plot points by hand.

1. Earthquake location data

The United States Geological Survey compiles a catalog of all earthquakes in the world of approximately magnitude > 4.2 and all United States earthquakes of approximately magnitude > 2. This catalog is openly available in a variety of searchable formats from this link: <http://earthquake.usgs.gov/earthquakes/eqarchives/epic/>

The first step in the activity is to create a small dataset from the USGS catalog by searching in a short time-window and small area centered around a subduction zone of interest. To take the Southern Andes subduction zone as a working example, appropriate parameters are for 6 months of data between latitudes 25° and 30° south and between longitudes 60° and 75° west. This search typically produces 25 - 30 earthquakes ranging in depth from 10 - 600 km. This time and area window is selected to maximize the probability that enough earthquakes of differing depths will be found, yet to produce a catalog that is not so large that the task of plotting earthquake locations by hand will be overly tedious for the students. For younger students or for classrooms without live internet access, an alternative approach is to compile the seismic catalog before class and hand out copies of the resulting text file to the students. Note that while individual subduction zones around the world tend to have fairly self-consistent rates of seismicity over time, seismic rates vary around the globe. For example, a 6-month catalog in the Southern Andes contains about the same number of earthquakes as a 2-month catalog from a similar window centered on the Fiji subduction zone. An extension of this activity for more advanced students asks them to consider some reasons for different seismicity rates at different subduction zones.

Once a catalog has been created, all participants plot the earthquake locations from their dataset on two maps. They first plot latitudes and longitudes on a traditional plan-view map in which the view is looking down on the surface of the Earth so that longitude is along the x axis and latitude is along the y axis. Secondly, they plot longitude vs. depth on a cross-section-view map, which is a planar slice perpendicular to the first map so that longitude is along the x axis and depth is along the y axis.

Students are asked to examine their maps and discuss the observations that can be made regarding earthquake locations with respect to depth. Specifically, they are asked to make a claim about why the earthquakes are where they are. The following question prompts are designed to help students come up with the evidence needed to support or refute the claim they made.

- Look at your cross-section map. Describe the trend of earthquake locations with respect to longitude and depth. Describe the patterns you see.
- How can we infer the location of the plate boundary from this data?
- How can the earthquakes patterns be used to infer the kind of plate boundary at this site?
- What is going on at this plate boundary to cause these earthquakes?
- Use these observations, together with some scientific reasoning, to support your claim about why the earthquakes are where they are.
- By looking at the earthquake locations, how can we infer the directions that each plate is moving at this plate boundary?

After the students have had time to reflect on their maps and work through their reasoning involving the mechanics of subduction as inferred from earthquake locations, it is time to introduce the second piece of corroborating data: locations of arc volcanoes.

2. Volcano Location Data

This part of this activity involves adding the locations of known volcanoes on the two student maps of earthquake locations. Information about Earth's active volcanoes is openly available through the Smithsonian Institution's Global Volcanism Program. To continue with the example of the Southern Andes subduction zone, the students are given the locations of the following five volcanoes. The exact link to the data used in this example is: <http://www.volcano.si.edu/world/region.cfm?rnum=1505>

Southern Andes Volcanoes

Tipas:	Latitude: 27.20°S	Longitude: 68.55°W
Peinado:	Latitude: 26.62°S	Longitude: 68.15°W
Cerro el Condor:	Latitude: 26.62°S	Longitude: 68.35°W
Unnamed:	Latitude: 25.10°S	Longitude: 68.27°W
Aracar:	Latitude: 24.25°S	Longitude: 67.77°W

Using a different symbol than the symbol used for the earthquake locations, students first plot the location of each of the 5 volcanoes on their plan-view map. Next, they plot the volcanoes on their cross-section-view map, using zero as the depth so that all the volcanoes are correctly located at the surface (see Figures 2 and 3 for examples of completed maps).

Once the maps have been completed, students are asked to observe the relationship between the earthquakes and volcanoes and use those observations to make a claim about why the volcanoes are located where they are. The following questions prompt the students in collecting the observations necessary to support their claim:

- Where are the volcanoes in relation to the plate boundary?
- Where would you draw the plate boundary on your plan-view map? How far are the volcanoes from this boundary?
- Two plates meet at this plate boundary. On which plate are the volcanoes?
- What spatial pattern do the volcanoes have on the plan-view map?
- How deep are the earthquakes under the volcanoes?
- Use these observations, together with some scientific reasoning, to support your claim about why the volcanoes are where they are and what might cause them.

This part of the activity may function as an introduction to the geometry of subduction zones as well as a discussion of the causes of arc volcanism. Students may observe that earthquakes directly underneath volcanoes occur at about 100 km depth (see Figure 3). This is approximately true at all subduction zones and can be a point of emphasis if students are broken into groups, where each group focuses on a different subduction zone. When the plate that makes up the deep seafloor

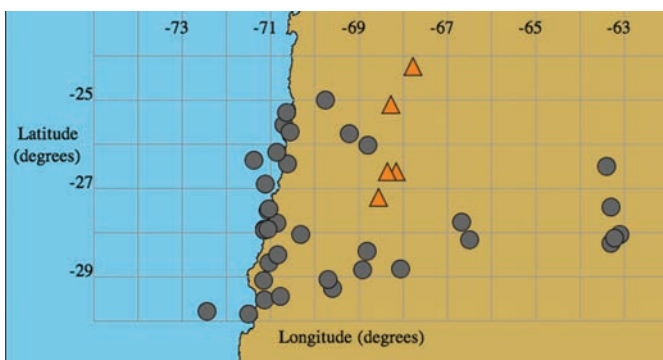


Figure 2. Map view of the completed exercise for the southern Andes. Area shown is the same as in the box labeled “Andes” in Figure 1. The South American continent is brown, and the Pacific Ocean is blue. Circles are the earthquake locations, and triangles are volcano locations. Students are given a map that looks exactly like this except that the earthquakes and volcanoes are not plotted. It is an exercise for the students to plot the longitudes and latitudes of each earthquake and volcano by marking them on this map.

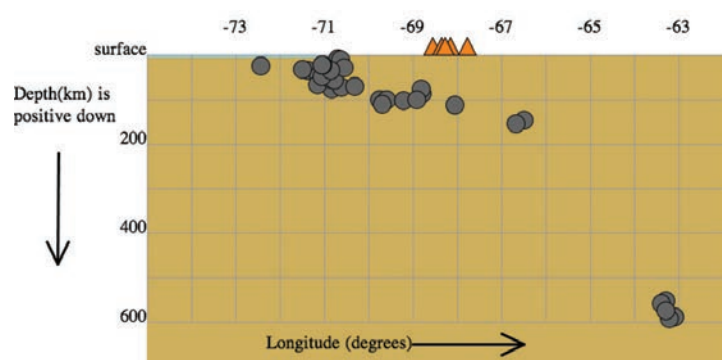


Figure 3. Cross-section view of the completed exercise. The solid Earth is brown and the liquid ocean is a thin sliver of blue located at the top left of the cross-section. The earthquake locations approximately denote the boundary between the sinking plate and the overriding plate. Note that the earthquakes immediately below the volcanoes are at approximately 100 km depth (see text for discussion). Students are given a map that looks exactly like this except that the earthquakes and volcanoes are not plotted. It is an exercise for the students to plot the longitudes and depths of each earthquake and volcano. Note that geophysical boundaries are purposely not drawn on this map because a learning objective of this exercise is that students will discover that earthquake locations allow scientists to infer the location of the plate boundary at depth in a subduction zone.

subducts, it takes some water along with it. This water is eventually forced out of the rock of the sinking plate. At about 100-km depth, the overlying mantle rock is hot enough that any water added will cause the rock to melt because water lowers the melting temperature of rock. The magma then percolates upward and feeds the arc volcanoes on the surface. Since arc volcanoes occur at the location on the upper plate that is directly above the point at which the lower plate equals 100km depth, students can sketch a right triangle on their cross-section map (Figure 3) that connects the trench, the volcano locations and the earthquakes at 100km depth on the lower plate. Students may then be prompted to consider some basic points about the geometry of subduction zones:

- If the lower plate were diving less steeply, but the volcanoes are always above the 100-km depth mark, then would the volcanoes be closer to or farther from the trench?
- If the lower plate were diving more steeply, would the volcanoes be closer or farther from the trench?
- How could you guess how steeply the lower plate of a subduction zone is diving if you only had a plan-view map, but you didn't have a cross-section map?

The goal of this last part of the exercise is for students to reach the conclusion that the distance between the plate boundary (trench) and the arc volcanoes tells scientists the angle at which the lower plate dives beneath the upper plate. If this activity is used as a jigsaw activity with a variety of subduction zones, students will be able to compare their results and observe first-hand that the lower plates of different subduction zones dip at different angles. Another observation that may be made is that the ocean is an extremely shallow feature of our planet when compared to the overall size of our planet. At the scale of the cross-section map in Figure 3, the ocean was plotted as a 5 km-deep layer, which is actually a slight exaggeration, and yet it is still so thin that it is hard to see at the top left of the map. Most of the cross-sections students see in textbooks have an imagined 3D perspective with much vertical exaggeration and a sharp delineation of all geophysical boundaries. The point of this exercise is for students to discover that the locations of earthquakes are the clues that allow scientists to draw the boundaries in the correct places.

Discussion and Conclusions

This activity stresses the skills of data manipulation, plotting, and visualizing locations on a map. In addition, students must infer Earth processes from remotely collected data using scientific reasoning, which is an important skill in any field of science, but particularly Earth and Space science. The goal is to provide students with the foundation of an accurate mental model regarding what manifestations of plate tectonics do happen at subduction zones, where they happen in relation to each other, and how that information gives scientists better understanding about the mechanics of convergent margins.

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About the Author

Eliza Richardson earned her bachelor's degree in Geology and Geophysics from Princeton University and her PhD in Geophysics from MIT. She is currently an assistant professor in the Department of Geosciences and the director of the M.Ed. in Earth Sciences program at The Pennsylvania State University, University Park, PA. Her current research focus is on the spectrum of fault slip in subduction zones. Eliza can be reached at eliza@psu.edu



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On August 3, 2012, this image of a very severe and fast moving bow echo was taken as the storm moved down the highway from Redfield to Watertown South Dakota. Forward speed of the bow was around 60mph and winds of at least 80mph accompanied the bow in some areas, with many trees uprooted, poles snapped, grain bins destroyed and buildings moved off foundations. The photo was taken by Mike Hollingshed, using a Canon T2i, Canon 10-22 EF-s at 11mm 1/40th F4. To see more of Mike's work, go to <http://www.extremestability.com/>