ASTRONOMY BEAT

Authentic Research in Science Education and Outreach

Don McCarthy *(University of Arizona)* and Jeff Lockwood *(Technical Education Research Center)*

Will high school science teachers, fired up from working on high-powered university research, inspire more student interest in science?

In 1988, this question was posed and answered by the High School – College Research Partnership Program funded by the Research Corporation (RC). We were fortunate to be one of 32 teams in their pilot program. In hindsight, the effects have been far-reaching on our students, on us, and on the modern landscape of science education.

Don learned of the partnership opportunity at a 1987 Christmas party. The RC's Grants Program Coordinator, Brian Andreen, asked Don if he would be interested in partnering with Jeff Lockwood, a 17-year veteran physics/astronomy teacher from Tucson's Sahuaro High School. Don already included high school interns in his research. Why not involve a teacher?

Back then the public did not participate in science. Research facilities were restricted or only viewable behind Plexiglas windows. Contact with scientists was rare. Research proposals to agencies like NSF and NASA were not required to have educational or impact statements, and the idea of enhancing an existing grant to support education had not been conceived.

We received a $5,000 Flinn Foundation Grant to explore nearby stars for infrared emission from low-temperature companions, perhaps brown dwarfs or planets. Jeff and Don met in 1988 before their summer began. Afterwards Jeff was excited.

Astronomy student Orianna Bretschger was pretty good at landing the shuttle from a height of 100,000 feet. Since Jeff Lockwood didn't play video games, he crashed the shuttle every single time, much to the delight of his students. *[Jeff Lockwood]*

You know you really caught me by surprise the other day. I had no idea that I would be allowed to really 'do' research. I am excited as hell about it! I feel like a kid in a candy shop, to be quite honest. I realize that this is a super-rare opportunity to dive into something and get my brain 'dirty' (instead of my hands) digging around into what I call 'hard science' — a.k.a. research.

Data Can Be Inspiring

During the same summer Don employed a rising eighth-grade student (Johnna Nichols) to process an extensive dataset from 21 temperature sensors characterizing the behavior of the Multiple Mirror Telescope (MMT). Slow variations in temperature during the night were causing small shifts in the alignment of the six 1.8-meter telescopes. Minimizing these shifts would allow the MMT to operate as a so-called phased 6.9-meter aperture, yielding the sharpest images in the world. One day, Jeff saw a huge pile of this raw data and got an idea.

Jeff Lockwood and Don McCarthy examine a scale model of the 6.9-meter Multiple Mirror Telescope showing the six separate 1.8-meter telescopes on a single mount. *[L. Stiles]*

All of a sudden it occurred to me that it would be great to give it to my high school class and say "Okay, here's the problem, here's the data, what are you going to do with this data? And once you decide how to handle the data, what are your conclusions? Here's the problem and it's real."

Jeff used the MMT data as a month-long assignment in his astronomy class. He immersed students in 800 pages of numbers and let them work together to help optimize the MMT. By informing the students they would report their results to McCarthy and to Irwin Shapiro (Director of the Center for Astrophysics), the project became even more real.

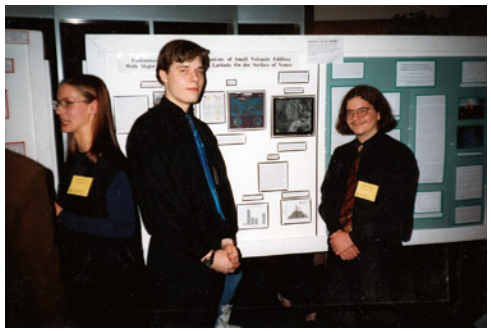
"Research" is…

Jeff was surprised to discover that: *Students believe that scientific research is identical to literary research…. They have no sense at all of what the scientific method is. To them, research is clinical, dead, and mostly involves digging up old information and using it to "improve our lives."* After their experience, students used words such as fun, educational, tedious, tiring, challenging, satisfying, and addictive, and added: *Doing research makes you feel good because you get something done on your own.*

With continued RC support, Jeff created an official course in astronomical research at Sahuaro. The students examined extensive datasets relating to volcanoes on Venus, oceans on Mars, and variable stars, enlisting other scientists as mentors including Sallie Baliunas, Janet Mattei, John Percy, Robert Strom, Goro Komatsu, Jeff Kargel, and Jeff Johnson. From 1990-95, during a week in spring, the student teams traveled to Houston, TX, to present and defend their research in front of scientists at the Lunar and Planetary Science Conference. Proudly, Jeff remembers:

Astronomy Research students assembling their posters at the 1995 Lunar and Planetary Science Conference (LPSC). *[Jeff Lockwood]*

Orianna Bretschger at our poster at the 1995 LPSC. *[Jeff Lockwood]*



Kathyrn Arbeit, Kyle Gerlach, and Mike Safford in front of their paper at the 1994 LPSC. *[Jeff Lockwood]*

Scientist Spotlight: Orianna Bretschger

[Courtesy JCVI.]

Most of us have never thought about how to make more water or cleaner water or develop unique sources of energy, but that's exactly what Orianna Bretschger does at J. Craig Venter Institute (JCVI). She is working at the intersection of engineering, physics, and biology to design small machines powered by bacteria that can purify wastewater and generate electricity at the same time.

Orianna always had an interest in science, especially astronomy. Thanks to that interest, coupled with good teachers who always inspired her, she found her way to where she is now.

At an early age, Orianna entered the Young Astronauts program. By junior high she had attended two International Young Astronauts conferences, toured the Johnson and Kennedy Space Centers, and traveled to the former USSR with her mentors and another student to help build relationships with Young Kosmonauts.

In high school she expanded her science interests to physics and planetary science, and had the opportunity to present a poster at a Lunar and Planetary Science conference at the Johnson Space Center in Houston. Her teacher (Jeff Lockwood) encouraged her to go to Northern Arizona University in Flagstaff, AZ, where she earned a merged degree in physics and astronomy.

After her undergraduate education, Orianna landed a job at Raytheon Missile Systems in Tucson, Arizona, where she worked on guidance systems, supporting projects in the electro-optical subsystems department. After two years at Raytheon, she moved to Authenti-Corp, a company that is involved in biometrics evaluation. Here her primary job was working with the Department of the Army Biometrics Task Force to develop policies and procedures for biometric systems testing and implementation.

Orianna returned to school, attending the University of Southern California's Materials Science PhD program in the School of Engineering. Graduate work was focused on identifying the specific genes in the organism Shewanella oneidensis MR-1 (a bacterium which can reduce poisonous heavy metal and can live in environments both with or without oxygen). She also had the opportunity to learn and practice microbial physiology, reactor design, electrochemistry, analytical chemistry, and environmental engineering. She graduated in 2008, and then joined JCVI.

Currently her interests are to extend the technology for sustainable wastewater treatment, energy recovery, and develop systems for the study of microbial physiology. Ten years from now she hopes to be tenured faculty, and believes her work with engineered and biological systems will ultimately contribute to developing healthy and sustainable water management practices throughout the Southwest and worldwide.

Dr. Bretschger is an Assistant Professor in the Electromicrobiology group within the Microbial and Environmental Genomics department at the J. Craig Venter Institute, San Diego. This segment was adapted from an article by Karen Nelson, Director of JCVI's Rockville campus. Reprinted with permission.

In a crowd of 600 attending scientists, they were the only high school students there. Their presentations are the highlight of my teaching career.… I watched them as they took turns explaining their research to planetary astronomers and others, who commented favorably and critically about their work.

After several years, it became apparent that this research-based teaching model motivated and engaged all types of students, and that success was not pre-determined by prior academic ability or gender. Several low-achieving students thrived in this new environment, even though the research class convened at 7:00 am, before school began! In today's parlance, the experience promoted a growth mindset. From the students, *It was the first chance I had time to really think about, and work at, solving a problem* — a problem they owned, but neither students nor teacher knew the answer.

Today, as his class of 1991 reflects on their experience, their comments confirm Jeff's conclusion that if high school students could experience the dynamic nature of discovery-oriented scientific research, many more of them would choose it for their career field.

Erik Timmerman, now a scientific programmer at the National Optical Astronomy Observatory (NOAO) and formerly with the Phoenix mission to Mars and the Lunar Reconnaissance Orbiter (LRO), said: *That whole process was the first time I went off on my own, although with lots of support, to learn about something I thought needed to be investigated. Dr. Lockwood's class gave me confidence and direction to choose science as my career. His kindling of my love of science has turned into roaring fire for the pursuit of knowledge.*

According to student project leader Leisa Glennie: *The class changed the course of everything. To be given a research problem by a teacher, and then to learn the teacher not only doesn't know the answer to that problem, but that there might not be one at all — that was life changing. I learned how very many unknowns there are in the daily life of a research scientist, and that those unknowns were what made it so exciting.* Leisa also described the impact of her experience in an article in *Mercury* magazine.

Applying the Model Nationally

Jeff disseminated the concept of research in the classroom through published articles and by involving other teachers and students at Sahuaro in topics like biochemistry, and at Evergreen High School in Washington State in exploring small volcanic edifices on Venus. In 2000, he received the Thomas J. Brennan Award from the Astronomical Society of the Pacific (ASP) for exceptional achievement related to the teaching of astronomy at the high school level.

In 1996, Jeff and Don helped initiate the NSF-funded Research-Based Science Education (RBSE) program at the National Optical Astronomy Observatories as co-PIs under the direction of Suzanne Jacoby and later Stephen Pompea. For 10 years RBSE, and its successor program (Teacher Leaders in RBSE), engaged more than 150 middle and high school teachers in astronomical research at Kitt Peak, the National Solar Observatory, and the Spitzer Science Center so that the teachers could then develop their own research courses back home and also mentor their colleagues. Like Lockwood, several of these teachers also received the ASP's Brennan Award: Steve Rapp (2005), Thomas Morin (2006), Ardis Herrold (2009), and John Blackwell (2010).

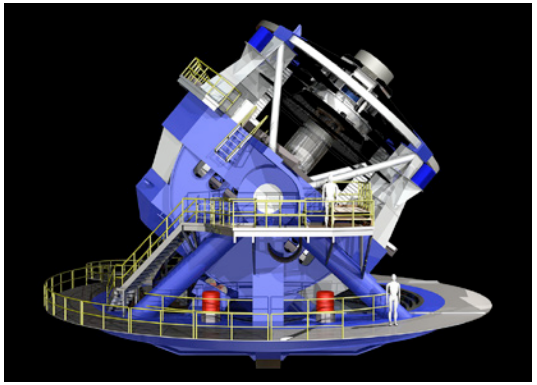
Five Sahuaro students from 1991 pose with their teacher, proudly showing off their completed research. *Left to right:* Scott Sims, Jeff Lockwood, Leisa Glennie, Ira Citron, Laura Bartsch, Brian Delong. *[Leisa Glennie]*

Research in Today's Science Education Community

In contrast to 1987, today's scientists seek out the involvement of students, amateurs, and volunteers. NASA missions such as Stardust, Kepler, LRO, Chandra, and Spitzer have provided opportunities to analyze real data, and non-professionals have discovered supernovae, odd nebulae, and exoplanets. The public also has access to multi-wavelength images of the entire sky through the Sloan Digital Sky Survey, Google Sky, and the World Wide Telescope, and can obtain their own data with remote telescopes.

Originally a RBSE postdoctoral fellow, Travis Rector has involved thousands of college students in RBSE research projects, discovering more than 100 novae in the Andromeda galaxy and recovering 96 asteroids and Kuiper Belt Objects. He has also helped extend the program to eight universities and community colleges.

Suzanne Jacoby, the original RBSE Director, is now the Education Director of the Large Synoptic Survey Telescope (LSST), which will produce a sensitive map of the sky every week to reveal time variable phenomena. The pinnacle of authentic opportunities in astronomy will literally come online in 2021 when LSST releases its first images, enabling anyone to discover faint, time-variable, and moving objects nearly in real-time.



The 8.4-meter Large Synoptic Survey Telescope will use a special three-mirror design, creating an exceptionally wide field of view and will have the ability to survey the entire sky once a week. *[LSST Corporation]*

A key to success in formulating authentic research projects is finding an enthusiastic scientist or graduate student mentor as we did in our programs. Given today's broader acceptance of amateurs and the utility of the Internet, finding and involving mentors should be easier. NASA now coordinates more than 1,000 scientists, educators, and outreach professionals in their efforts to convey the excitement of NASA missions and to build a strong foundation nationally in science, technology, engineering, and math (STEM). The IAU has even created a special membership category for professionals in astronomy education/communication.

RBSE and TLRBSE teachers continue to use a number of different pedagogical models to shoehorn projects in their classes. During the course of a semester, one day a week can be Research Day. Or most of the project can be done for homework, as were our first efforts. Some teachers do research in science clubs after school, or use their planning period to run independent study projects. Others set aside four weeks at the end of the school year to provide a project that acts as a final performance assessment for the year. These teachers have found a way to provide a research experience that fits their particular classroom situation.

Students as Scientists: An Uncertain Future

In our experience spanning a quarter century, students of all ages are clearly inspired by collaborating with real scientists and working on authentic data. NASA missions and scientists have been exceptional in capturing our students' imagination, motivating and enabling them to become research scientists, engineers, and educators.

Recently, the President's 2014 budget proposes to eliminate NASA's education and public outreach programs. This act will make engagement between scientists and students much more difficult and less frequent at a time when STEM education is acknowledged to be crucial. It would be a shame to suppress the vital role NASA plays in inspiring the next generation of scientists, engineers, and the public in general.

One thing is certain. Without actually *participating* in research, our students never experience the excitement or feel the thrill of discovery, and they never really understand what research and science are. As Deborah Port (1990) states: *Students discover gifts in science by trying their hands at it, providing they have a chance to do so.*

Sahuaro research students with Jeff Lockwood (back left) stand in front of their project, created for the 1991 LPSC conference. *[Photographer unknown.]*

About the Authors

Don McCarthy is a research astronomer and lecturer with Steward Observatory at The University of Arizona. He specializes in infrared astronomy and engineering and has been passionately doing science education at all age levels throughout his life. He brings research to the general public via his Astronomy Camp programs and Camp-like workshops with adult Girl Scout leaders by directing the education program for NIRCam on the James Webb Space Telescope.

Jeff Lockwood currently works for the Technical Education Research Center (TERC) in Cambridge, MA. During the past 20 years he has focused on using science data to do classroom research by developing curriculum and professional development programs. He has authored curriculum materials for National Science Foundation programs such as *Project STAR, Hands-On Universe, Hands-On Astrophysics, Eyes in the Sky, Astrobiology, Physics That Works, and Investigating Astronomy.*

Resources

- Review Highlights Role of Citizen Science Projects, 12 Nov. 2012, BBC News. http://www.bbc.co.uk/news/science-environment-20445296
- Coming Full Circle, Glennie, L., 1997, Mercury, 26, #2, 7. http://www.astrosociety.org/pubs/mercury/9702/glennie.html
- Research in the Classroom: An Informal Account of a New Way to Learn Science, Lockwood, J., 1992, I.A.P.P.P. Communications, 46, 57-62. http://adsabs.harvard.edu/abs/1991IAPPP..46...57L
- Oceans on Mars: A Crater/Frequency Analysis by Elevation of the Northern Plains; Sahuaro High School Astronomical Research Classes of 1991, J.F. Lockwood, 1992, LPSC XXIII, 23, 1199-1200. http://articles.adsabs.harvard.edu/full/seri/LPI../0023/0001199.000.html
- Citizen Science and Opportunities for Student Research: https://www.zooniverse.org and www.scientificamerican.com/citizen-science ✦

Astronomy Beat

Number 113 • July 17, 2013

Publisher: Astronomical Society of the Pacific
Editor: Paul Deans
Designer: Leslie Proudfit

The Astronomical Society of the Pacific increases the understanding and appreciation of astronomy by engaging scientists, educators, enthusiasts and the public to advance science and science literacy.

astrosociety.org

390 Ashton Avenue, San Francisco, CA 94112

ENSURING STEM LITERACY

This month the ASP organizes and celebrates its 125th Annual Meeting for science educators and public outreach professionals. We wish to thank attendees, sponsors, exhibitors, and volunteers — all vital to the success of the event and to the ongoing advancement of science education and science literacy!