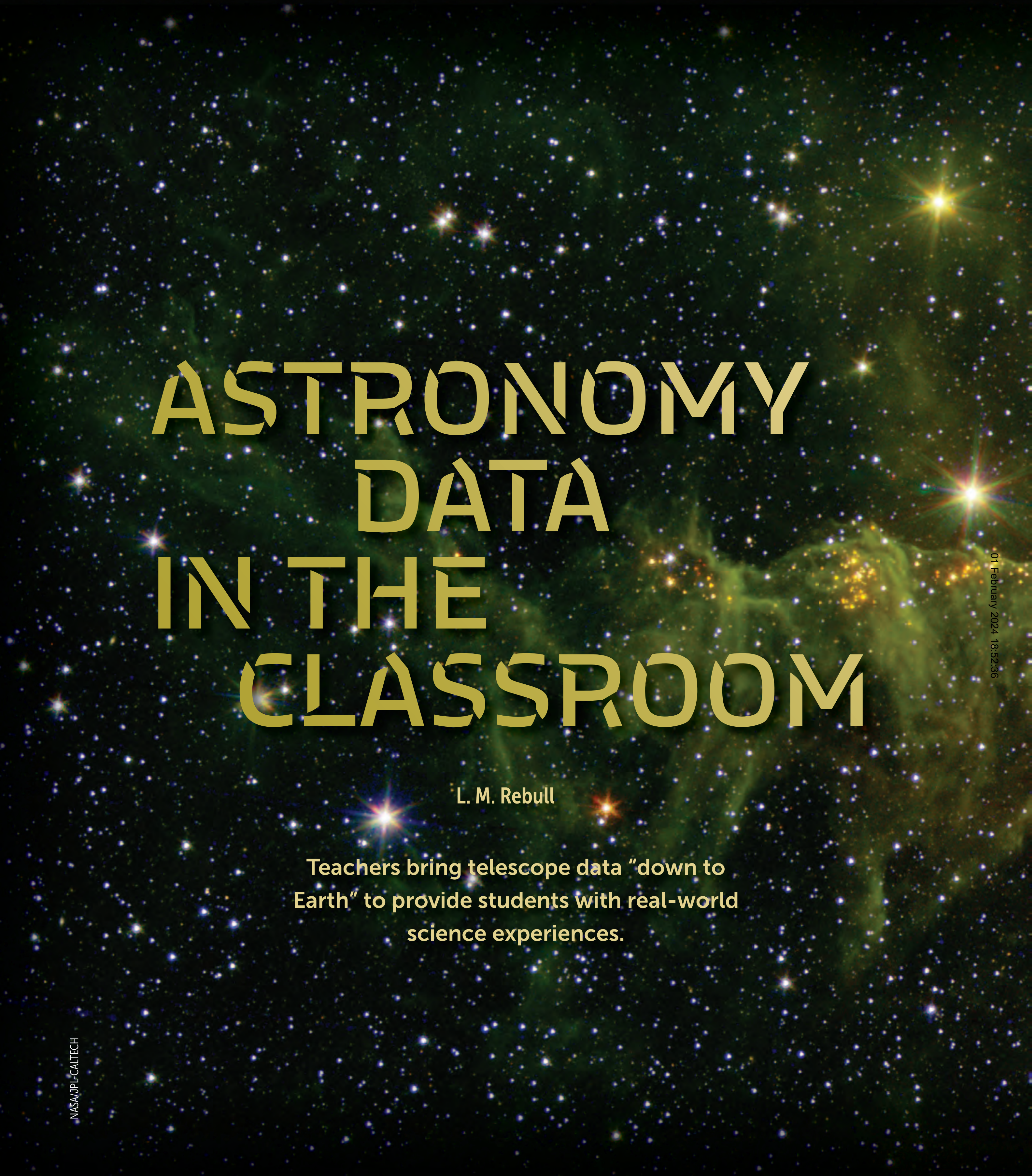
AIP
PHYSICS TODAY

Astronomy data in the classroom

Teachers bring telescope data "down to Earth" to provide students with real-world science experiences.

L. M. Rebull

Physics Today **77** (2), 44–50 (2024);
https://doi.org/10.1063/pt.vlhh.iudp



NASA/JPL-CALTECH

ASTRONOMY DATA IN THE CLASSROOM

L. M. Rebull

Teachers bring telescope data "down to Earth" to provide students with real-world science experiences.

Luisa M. Rebull (rebull@ipac.caltech.edu) is a research astronomer at the NASA/IPAC Infrared Science Archive at Caltech in Pasadena, California. She has been working closely with high school teachers for nearly 30 years, most recently through NITARP, the NASA/IPAC Teacher Archive Research Program.

I will never forget the first science teacher training workshop I attended. I was in graduate school in astrophysics at the University of Chicago, and the Adler Planetarium hosted the workshop. We were given an image of the Sun with a large prominence at the lower right. After a brief introduction to the software, we were asked how many Earths fit underneath the prominence, given the image's pixel scale. I measured the prominence's height radially, calculated the ratios, and figured that it was about three Earths high. Simple enough, I thought, and I started to look around me. The gentleman to my right was completely overwhelmed. He had no idea how to approach the problem and resorted to telling me about all the teaching awards he had won.

THE 2022 NITARP TEAMS during their summer visit to Caltech. NITARP is a program that partners small groups of educators and students with a research astronomer for a 13-month-long authentic astronomy research project. It also includes a summer research trip. Here, one educator is experiencing an "aha" moment when something finally "clicked." (Courtesy of David Friedlander-Holm/Luisa M. Rebull.)

When we reconvened and shared our measurements, I discovered that many of the participants had interpreted "underneath" in strictly Earth-based terms—that is, up and down on the screen. Even those of us who determined "height" in the same way arrived at slightly different numbers, and we launched into a fascinating discussion of measurement error. Many participants were uncomfortable with there being so many correct answers.

All of those things—working with real data, angular measurements on the sky, ratios, significant figures, measurement error, and even determining which direction is "up"—are second nature to professional astronomers, but maybe not for many or even most middle and high school teachers.

Science teachers in the US, thanks to the Next Generation Science Standards, are now being asked to teach science in ways that they themselves were not taught—using real data and approaches that more closely mimic those of scientists.[1] There is a demonstrable need for teachers—and, therefore, students—to have an opportunity to do stuff that we, as trained scientists, take for granted. Astronomy is special among the sciences in that the public is already considerably interested in it, and multiple petabytes of multiwavelength research-grade data are available online for free to anyone. There are many ways to access those data, at many different levels, suitable for elementary through college students, educators at all levels, and the general public. Let's dive in!

Citizen science on the Web

The easiest way to start working with real astronomy data is to explore some of the many Web-based citizen-science programs out there. They are designed to give users a fun experience and inspire them to seek out more ways to work with scientific data. Zooniverse hosted one of the first—and is still home to some of the best—projects, and it has citizen-science programs in far more disciplines than astronomy, although it always has several space-related ones running at any given time. All you need to get started is an internet connection and a Web browser. The programs have well-defined tasks for participants, and Zooniverse provides all the training and tutorials you need to help with its projects.

Anyone from children to senior citizens can participate and make real contributions; no one needs advanced astrophysics knowledge to understand what they are looking for. You can help as little or as much as you want, and some "citizens" have been coauthors on journal articles that have emerged from their work. Zooniverse has ready-made activities for classrooms, or you can design your own. For some teachers, though, the activities may seem too polished and may not be enough of a challenge for students, so they won't absorb the deeper meaning of the tasks they are doing.

Many programs let you use astronomy data for canned labs. Hands-On Universe was one of the first programs to bring astronomy data into the classroom, back in the 1990s. Participants could use existing data in a structured framework or request new data from a network of participating telescopes around the world. (It was the source of the lab I used in the Adler teacher workshop mentioned in the introduction.) The program's activities—many still available online—enabled learners to determine angular sizes, explore the cosmological distance ladder, find supernovae, and construct Hertzsprung–Russell diagrams. Those activities still provide ways for novice learners to start working with real data, take their own measurements, and begin to understand why and how astronomers make quantitative measurements of celestial objects.

TWO STUDENTS, who were part of a 2023 NITARP team, compare results for the detailed calculations that they made to plot spectral energy distributions.

A more recent example of a program working with real data is the Vera C. Rubin Observatory education group. Although the observatory hasn't seen first light yet, the education group has already prepared several online lessons, using placeholder data, for classroom use now. When the data start flowing in earnest, real Rubin Observatory data will be added to those online lessons, in sufficient quantity so that all students in even large classes will get "their own" data to use. The lessons explore asteroids, cosmology, the solar system, and dying stars, and more are planned. Once again, just a Web browser is needed. Importantly, the educational group has worked to put the infrastructure in place to allow teachers to run (and easily grade) labs for large groups of students, in which each student, or each pair or trio of students, is working with different data and will come up with different answers. The group has also provided connections to the relevant Next Generation Science Standards.[2]

Student-collected data

Even the canned labs that use real data don't usually require more than a Web browser. More advanced programs, however, assume a more advanced level of understanding. Some programs facilitate students collecting their own data by granting remote access to a telescope.

One such program, which is almost as old as Hands-On Universe, is the MicroObservatory Robotic Telescope Network, operated by the Center for Astrophysics|Harvard & Smithsonian. Its most recent effort enables students to search for exoplanets. It provides the scaffolding needed to help learners contribute their real data to the archive and combine their own data with others' to find the exoplanet transit signal. That would not be an easy task done on their own because a planet transit represents at most a few percent drop in the light from the star. Conducting photometry that precise is challenging, especially for beginners. Within the scaffolding established by the program, however, participants can do a straightforward analysis using just a Web browser.

A more open-ended example is the Skynet Robotic Telescope Network, out of the University of North Carolina (UNC) at Chapel Hill. It was established for research purposes, but a substantial fraction of the observing time goes for educational purposes, such as undergraduate classes at UNC-Chapel Hill and other schools, Skynet University, Skynet Junior Scholars, IDATA (Innovators Developing Accessible Tools for Astronomy), and other curricula for college and advanced high school classes. Participants can request data from the telescope network as part of a class or program. And the software developed by UNC-Chapel Hill, known as Afterglow, enables that request plus the analysis required to, for example, create three-color images with optical images alone or in conjunction with archival IR images, perform photometry, and analyze the results. The scaffolding provided by the curriculum builds skills that could be leveraged into independent research projects for science fairs.

More astronomy for your classroom

I have collected all the programs I know about that get data into the hands of middle and high school teachers and students here: https://nitarp.ipac.caltech.edu/page/other_epo_programs.

The list is long. Not everything on it is still running. All involve access to real data, but they populate a rather large parameter space—the literal spectrum of light, the spectrum of interaction with professional researchers, and the spectrum of using someone else's data access and management software or developing your own. Some allow for lots of interaction with the people who run the program, and some depend on your ability to read the documentation they've provided and learn on your own. That is the case especially for the programs that are no longer actively running but keep their materials available on their website.

Some have geographic restrictions, but many do not. The list focuses on precollege students specifically because myriad opportunities are readily available to college students doing research. If you know of more programs for precollege teachers or students that I have missed, please let me know and I will add them.

There are also various ways to introduce real data or research into the classroom, aside from working with either via any of the methods described here.

NASA's Astronomy Picture of the Day (https://apod.nasa.gov/apod/astropix.html) uploads a new image daily with a brief explanation of what it is and why it matters. The site also has resources specifically for educators. Simply having the site up while students assemble in the classroom can spark conversations about current events or results.

The site Astrobites (https://astrobites.org) takes one article per day and summarizes it in language suitable for upper-level high school and undergraduate-level readers. The authors are current graduate students. They focus on new research, historical work, or other issues of importance to the community. They also write summaries of American Astronomical Society (AAS) meetings during the meetings, including press events.

You can follow the AAS press office (https://aas.org/press) on social media or subscribe via email to get copies of astronomy-related press releases, which are written for the general public. The press releases about articles in AAS journals, which are now all open access, include links. The Smithsonian Astrophysical Observatory/NASA Astrophysics Data System (https://ui.adsabs.harvard.edu/) includes the AAS journal articles among its 15 million publications records. The text of nearly all astrophysics papers can be found on the arXiv preprint server's astrophysics section (https://arxiv.org/archive/astro-ph).

Those kinds of programs are not just limited to the optical regime. NASA's Radio Jove Project asks participants to build their own radio telescope and then obtain observations of Jupiter, the Sun, and our galaxy. You can contribute your data to or explore data from the project's archive.

To take your own data and contribute meaningfully to a larger effort, you need to have a relatively deep understanding of what you are doing. Recently, because of progress in software, a high level of data quality can be achieved with only a Web browser. But even then, introducing young students to scientific research doesn't stop there.

Educating the educators with NITARP

Few current programs get real data into the hands of teachers and their students while also allowing them to participate in actual research. Such a program asks the most from its participants because it requires them to have sustained, deep interactions with the program organizers and a substantial understanding of the astronomy and astrophysics relevant to the project. But the interactions with organizers can fundamentally change the way that participants view science. One such program, which I helped found, started in 2005: the NASA/IPAC (formerly known as the Infrared Processing and Analysis Center) Teacher Archive Research Program, or NITARP. It partners small groups of mostly high school educators with a research astronomer for a 13-month-long (from January to January), authentic astronomy research project.

Who we work with

The "T" in NITARP stands for "teachers." If we work with only students, then our influence in a school ends when the students graduate. But if we work with educators, we influence the several hundred students they teach not just that one year but every year for the rest of their career. It is hard to beat the multiplicative effect. We know through our educators that we also reach other educators with whom they work in their school, district, and even state. Our participating educators are largely physics and astronomy teachers, but they also include chemistry, math, computer science, biology, and Earth-sciences teachers; museum educators; and other nonclassroom educators. Our participants—140 educators between 2005 and 2023—are from 42 states in the US and counting. Approximately 75% are high school classroom educators, and roughly 75% of them work in public schools.

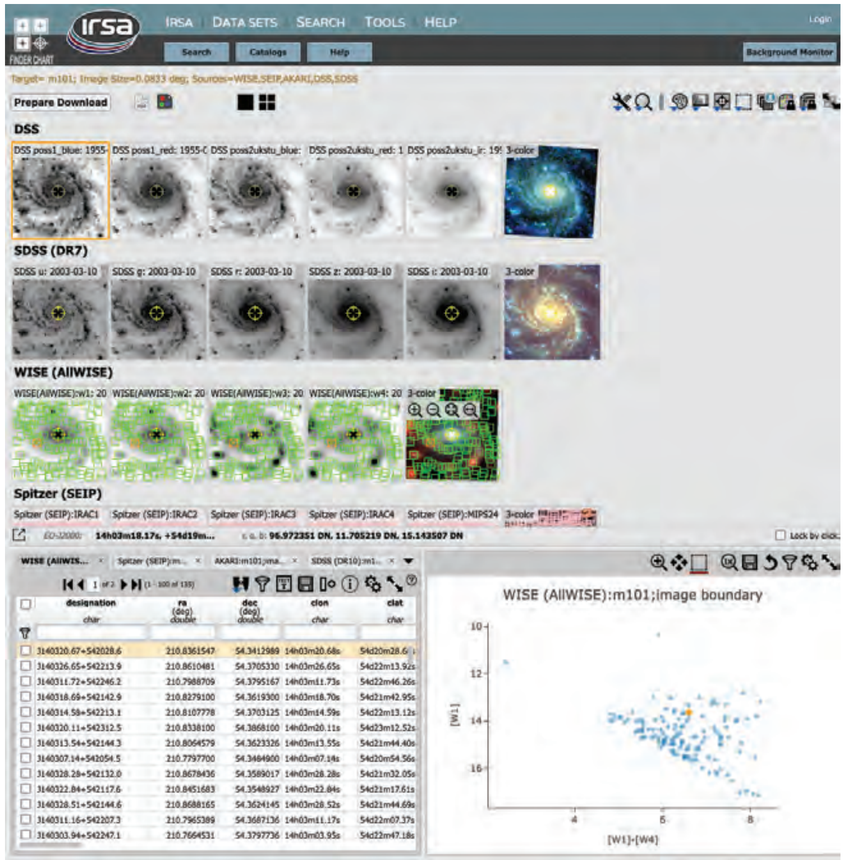
We don't systematically track our educators after they finish working with us, but we do have anecdotal evidence of the effect of NITARP on their students. One became the first African American woman to graduate with a degree in astrophysics from the University of Wisconsin–Madison, which is significant because there are so few Black women in the field. An autistic student selected by his teacher to participate wasn't initially interested in school at all; his family wrote to us because they credit NITARP not only with his graduating high school but with his starting community college. Sometimes the program has unexpected results; for example, a student from a wealthy community saw others going to school to become only medical doctors and lawyers, but as a result of NITARP, he was astounded to discover that those weren't his only choices for a career.

Research scope

The "I" in NITARP stands for "IPAC" and the "A" for "archive." All the NITARP teams work with archival data housed at Caltech-IPAC. Fortunately, a staggering amount of data is available, so there is no shortage of data to be found or science to be done. We do not ask teams to do advanced work—projects are comparable to what one might give a summer undergraduate. But the projects are also authentic science research, and as such, the teams don't always find what they set out to find. All the completed proposals and posters are available on the NITARP website, although coverage for some of the earliest years is spotty. As is the case for all conference posters (and summer research projects) everywhere, not all of them become journal articles. But some NITARP projects do,[3–5] and those are posted on the website.

To kick off the year, we give a NITARP workshop so teams can meet and start learning about their project. That happens just before the educators attend a January conference of the American Astronomical Society (AAS) to experience the largest astronomy meeting in the world and see how scientific discourse is conducted. Afterward, the teams go home and start working remotely. They write a proposal, which is peer reviewed by both educators and astronomers, and respond to the review. Final proposals are posted on the NITARP website.

The teams work remotely through the spring. In the summer, they visit us at Caltech; each educator can bring up to four students. Although the four-day trip may seem like a routine research trip for a professional scientist, it is often the first time that most participants have encountered days full of intense research. Students work and learn side by side with the educators on the trips. The teams make substantial progress on their project during the visit, but they rarely complete everything; they go home and keep working remotely. The abstracts for the January AAS meetings are typically due in early October, and each team makes at least two posters, one on the work's science and one on its education aspects. They then go to the January AAS meeting to present their results.



RESEARCH-GRADE ASTRONOMY DATA ON THE WEB. This screenshot shows the search results for the Messier 101 galaxy; they were created using a tool called Finder Chart, provided by NASA/IPAC Infrared Science Archive. Each image covers the same region on the sky; each row is from a different survey. The color image at the end of each row is constructed of that row's images. The colored points overlaid on the image are from the corresponding catalog and are shown as a table in the lower left and as a plot in the lower right. The image overlays, the table, and the plot are all interactive.

Influencing educators

There is high demand among secondary school educators for teacher experiences like those provided by NITARP. Five times as many educators apply to the program as there are spots available. That oversubscription ratio is par for the course in astronomy, and actually much better than what astronomers face when applying for time on some telescopes or for grants. But in education, specifically professional development, that is far from typical. Not only does NITARP have that kind of oversubscription, our alumni often raise their own money to return to the AAS meetings after their initial research project ends, continue to work with us on extensions of research projects, and find ways to get the research better integrated into their classrooms.

We have been doing this in one form or another since 2005, and so we have shaken out the bugs. We have begun to explore more rigorously the influence of our program on our educators.[6–9] The tendrils of NITARP's influence extend far beyond what we ever expected, and probably beyond what we know about. At least 14% of alumni say NITARP was life-changing and has shaped how they think about science and scientists and how they teach science. The sustained, long-term interaction among the participants—both scientists and educators—helps foster relationships between NITARP alumni beyond what NITARP can facilitate in a single year.

NITARP has had a significant role in the career changes of 10 alumni that we know of. Some have been promoted in their district so that they can influence science education at a higher level and with broader impact. Most importantly, 60% of alumni say NITARP inspired them to improve the way they include science in their classroom. Those changes are attributed by the educators to their NITARP experience.

Not much education research has been done on the effect that programs like those discussed here have had on teachers who participate in them. What research exists tantalizingly suggests that having teachers simply take part in authentic

There are many ways to incorporate astronomical data into a classroom at a range of expertise levels.

- Caltech-IPAC: https://www.ipac.caltech.edu/
- Hands-On Universe: http://handsonuniverse.org/usa/activities
- IDATA: https://idataproject.org
- IRSA: https://irsa.ipac.caltech.edu/frontpage
- MicroObservatory Robotic Telescope Network: https://mo-www.cfa.harvard.edu/MicroObservatory
- NASA Exoplanet Archive: https://exoplanetarchive.ipac.caltech.edu/
- NASA/IPAC Extragalactic Database: https://ned.ipac.caltech.edu
- NITARP: https://nitarp.ipac.caltech.edu
- Radio Jove Project: https://radiojove.gsfc.nasa.gov
- Skynet Robotic Telescope Network, Junior Scholars, and University: https://skynet.unc.edu, https://skynetjuniorscholars.org, https://skynet.unc.edu/introastro
- Skynet-Based Curricula: https://www.danreichart.com/curricula
- Vera C. Rubin Observatory education group: https://rubinobservatory.org/education
- Zooniverse: https://zooniverse.org, https://classroom.zooniverse.org/#

research improves student achievement.[10] Additionally, when educators are engaged longer in a program, it significantly increases the benefits they receive from it.[11] Other work explores how teachers' research experiences change their understanding of the nature of science, with a specific focus on astronomy.[12] Recent papers attempt to collect the literature and identify gaps in knowledge about how research experiences affect teachers and students.[13]

Improving access through archives

It used to be that astronomers went to a telescope, obtained their data, and took them home. (I remember once refusing to send computer data tapes through the x-ray detector at the airport on my way home.) We now don't have to go to a telescope to collect data, but even when we do physically visit an observatory, we still download them from an archive when we get home to reduce on our own computers. It is, however, getting to the point that the amount of data is too large to download at once. Archives are, right now and in real time, adapting to the reality that at least some analyses will need to happen within the archive, and some will be done at home.

The change is more equitable—a century ago, astronomy could be done only by those whose institution had a telescope. Starting about 40 years ago, publicly accessible telescopes were established in the US, so an institution didn't necessarily have to own a telescope for its scientists to do astronomy. On around that same time scale, the first publicly accessible astronomy archives were made available, and many more have since come online. People at smaller institutes or in smaller or economically marginalized countries can still do astronomy. Soon archives will have substantial publicly accessible computing resources and tools that can help all users—professionals and laypeople—perform computationally intensive analyses.

So many research-grade data sets are currently available on the Web for anyone to access. All the telescopes funded by US government money have a mandate to make their data publicly available. NASA has many more telescopes than just the headline-grabbing *Hubble Space Telescope* and *James Webb Space Telescope*, and all those data are free for the asking. NASA's telescopes make their data available in several archives. I work for the NASA/IPAC Infrared Science Archive, or IRSA. We must make our tools and data easy to access for all astronomers, including the emeritus professor who can barely read his email and the summer student embarking on her first research project. Because we have to meet the needs of all of them, we will also probably be able to meet your needs, although you will have to become familiar with IRSA tools and astronomy jargon (and you need Chrome or Firefox as your browser).

IRSA houses the original data from many of NASA's long-wavelength missions, and it has quite a bit of highly processed data that are ready to use for science. IRSA provides access to more than 700 billion astronomical measurements, including all-sky coverage in 24 bands. In total, IRSA hosts more than 8 petabytes of data from at least 18 projects. For approximately 15% of refereed journal articles in astrophysics annually, the authors used data curated at IRSA. And it is just one of eight NASA astrophysics archives—not to mention NASA's planetary archives and the other US and international astronomy archives. There are so many archives out there to explore.

I suggest starting with IRSA, though, in no small part because once you master our tools, you can access many of the rest of the world's astronomy archives via the Virtual Observatory protocols. Many tutorial videos introduce users to IRSA's Web-based tools, including ideas for how to use the tools for educational purposes. You can also write your own code to access IRSA's tools via application programming interfaces.

IRSA is just one of several archives at Caltech-IPAC; others include the NASA Exoplanet Archive and the NASA/IPAC Extragalactic Database. Both are focused on specific scientific goals and curate their data and tools accordingly.

With all those data available, there are countless possibilities for projects to introduce your students to the world of astronomy. Who knows what futures may be unlocked by including modern scientific research early in education.

REFERENCES

1. B. Wargo, *Phys. Teach.* **60**, 25 (2022).
2. A. Herrold, E. Prather, *Phys. Teach.* **61**, 536 (2023).
3. L. Rebull et al., *Astron. J.* **166**, 87 (2023).
4. L. Rebull et al., *Astron. J.* **150**, 123 (2015).
5. L. Rebull et al., *Astron. J.* **145**, 15 (2013).
6. L. Rebull, https://arxiv.org/abs/1804.08747.
7. L. Rebull et al., https://arxiv.org/abs/1804.08743.
8. L. Rebull et al., *Phys. Rev. Phys. Educ. Res.* **14**, 020102 (2018).
9. L. Rebull et al., *Phys. Rev. Phys. Educ. Res.* **14**, 010148 (2018).
10. S. Silverstein et al., *Science* **326**, 440 (2009).
11. T. Sadler et al., *J. Res. Sci. Teach.* **47**, 235 (2010).
12. S. Buxner, *J. Astron. Earth Sci. Educ.* **1**, 53 (2014).
13. J. Krim et al., *CBE—Life Sci. Educ.* **18**, ar65 1 (Winter 2019). PT