# Introduction

## Cal Poly Summer 2015 Astronomy Research and Development Seminar

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### Small Telescope Research and Development

Scientific research conducted with small telescopes is noted for the many professional and amateur astronomers who work together on research projects. They use small telescopes equipped with affordable instrumentation, and their research results are in published papers that significantly advance scientific knowledge. Examples of research areas of professional-amateur cooperation within astronomy include double star astrometry, variable star photometry, exoplanet transit photometry, and asteroid light curve photometry.

Small telescopes make their valuable contributions to astronomical research through time series, networked, and other observations that only large numbers of small telescopes with their amateur operators can provide. Small telescopes also continue to play a vital role in recruiting and training the next generation of astronomers and instrumentalists, and serve as test beds for the development of novel instruments and experimental methods. Advances in technology are favoring small-telescope science with increasingly effective and low-cost cameras, more numerous and efficient remote robotic telescopes, and more capable yet affordable computers.

It is widely agreed that small telescopes contribute significantly to astronomical research, both through direct research contribution and through their use in education. Weaver (2003) points out that

> Both quantitative and qualitative arguments demonstrate the continuing importance of small telescopes to the astronomical endeavor. The quantitative arguments show that it is significantly less expensive per citation to use the smallest telescope that will accomplish the research. Both the quantitative and qualitative arguments show that the research accomplished by small telescopes is of continuing and lasting significance to the discipline, as witnessed by their non-diminishing contribution to astronomy over the last century and the persistence of their citation histories.

Ringwald et al. (2003) point out that

> Small telescopes can hold their own with larger instruments since more time is available on them. This makes possible monitoring campaigns, aerial surveys, and time-resolved campaigns, particularly if the telescopes are networked or automated—all difficult to carry out with larger telescopes, for which even small amounts of telescope time are in great demand.

### An Experiment in Undergraduate Astronomical Research

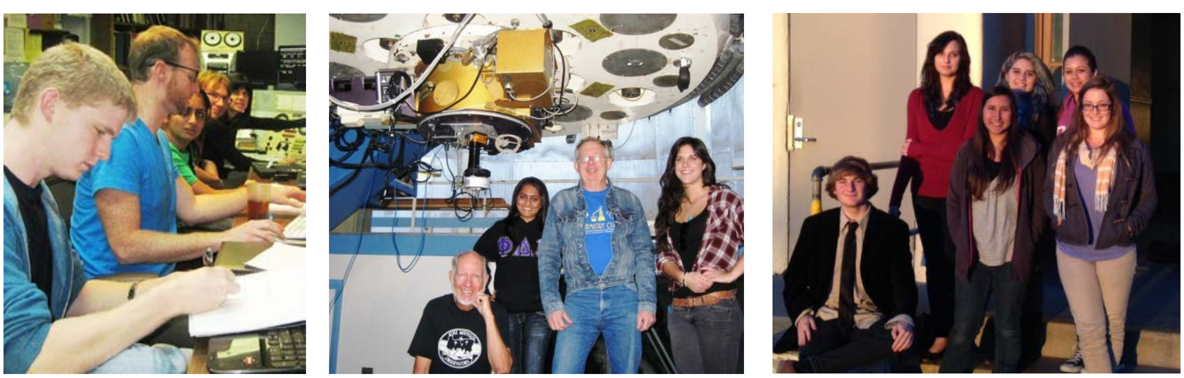
Shortly after my retirement from a quarter-century as a research and development supervisor at federal laboratories, I was teaching astronomy and mathematics part-time as an adjunct at the small, remote Superstation Mountain campus of Central Arizona College east of Phoenix. With free time on my hands, I decided to try an educational experiment. I was curious whether or not students could successfully conduct scientific research in a manner similar to the research scientists that had worked for me, but on more modest projects? Specifically, could the students:

- Learn science by doing science
- Plan and manage their own research as student teams
- Join a community of professional and amateur researchers
- Publish externally-reviewed papers in a specific research area
- Present their research results at a conference

Three student teams were formed, and they used a robotic telescope at my Fairborn Observatory to observe Delta Cepheid type variable stars over several pulsation cycles. All the experimental goals were met, except the “papers” were just abstracts in the Bulletin of the American Astronomical Society because the students ran out of time at the end of the semester to write full papers. The students stood by their posters at the Albuquerque AAS meeting in 2001. One of the students, Clay Lapa, a home-school student just starting community college, was only 16 years old.


*Students pose in front of an amateur’s half-meter telescope during an observing session.*

Declaring the first round of my experiment a “qualified” success, the experiment was continued, starting in 2006, at Cuesta College. By 2008, the seminar had focused on the astrometry of visual double stars, measuring their position angles and separations with increasingly sophisticated methods. The seminar was held on Cuesta College’s south “campus” which, during the day, was Arroyo Grande High School. The students were, primarily, high school juniors and seniors taking the Cuesta seminar after hours as their first college course. The students were supported by a growing community of professional and amateur astronomers, as well as a growing number of seminar graduates who continued their research after graduation and enjoyed helping new students learn the research “ropes.” What began as student observations of wide, somewhat bright observations with astrometric eyepieces, evolved into CCD observations of fainter doubles and, eventually, into highly sophisticated speckle interferometry observations below the seeing limit with high-speed electron-multiplying CCD cameras.



*Left: students control the 2.1-m telescope at Kitt Peak National Observatory, and (center) pose under the telescope. The speckle interferometry observations they made were cutting-edge astronomical research using a state-of-the-art EMCCD camera the team brought to Kitt Peak. Right: Cuesta College analysis team leader/high school student Bobby Johnson (seated on left) landed a four-year scholarship at Brown University, while Merle Adam (far right), was first author of their paper (Adam et al. 2015) and received a four year scholarship to Yale University.*

Collaboration with others led to replication of the successful Cuesta College astronomy research seminar in additional venues. In conjunction with the University of Oregon's Pine Mountain Observatory, a series of highly concentrated summer seminars was initiated that resulted in a number of published papers by both high school and undergraduate students (e.g. Schrader 2010, Baxter 2011, & Brashear 2012). Soon the seminars' most seasoned and active graduates co-edited books (Genet et al. 2010, Weise et al. 2015) and co-chaired conferences, culminating in the Maui International Double Star Conference (Weise et al. 2015).

These seminars have, over the past eight years, yielded some three dozen published papers (with over a dozen more in the pipeline) coauthored by more than 100 students (e.g. Marble et al. 2008, Dowdy et al. 2009, & Estrada et al. 2010). The students' measurements have added many published double-star measurements to the permanent archive of the Washington Double Star Catalog maintained by the U.S. Naval Observatory.

Seminar students have co-edited four books: *Small Telescopes and Astronomical Research* (Genet et al. 2010), *The Double Star Reader* (Clark et al. 2014), *Speckle Interferometry of Close Visual Binaries* (Genet et al. 2015a), and *Double Star Astrometry: Collaborations, Implementations, and Advanced Techniques* (Weise et al. 2015). The seminars' graduates have co-chaired many workshops as well as three major international conferences: Galileo's Legacy in 2009, Small Telescopes and Astronomical Research in 2010, and the Maui International Double Star Conference in 2013.

## Lessons Learned from the Undergraduate Student Research Seminar

The success of the student research projects resulted from, primarily, simply following the normal "rules" of scientific research. These practical rules are often only learned as a graduate student, post-doctoral researcher, or even later. Frustrated that so many doctoral students were graduating without learning the basic "ropes" of being a scientist, Peter Feibelman (2011) developed a course he turned into the classic book, *A PhD is not enough! A Guide to Survival in Science*. Although I made several attempts to "soften" science's rules to make it easier on my seminar students, it was found that this undermined the core strength of the research seminar. Science, a highly successful form of cultural evolution, has developed its many rules for good reasons. Students like to know that they are doing the real thing, not some watered-down version that they are likely to interpret as condescending. The primary lessons learned so far from this long-running student research seminar "experiment" have been:

- Research should be conducted within a supportive community of practice, typically within a narrow specialty. Astronomical research with smaller telescopes works well—especially research such as double star astrometry where the observations can be completed in a single evening or economically by a remote robotic telescope.
- Research must be original and be published as papers in appropriate (specialty) journals reviewed and read by the members of the relevant community of practice.
- Projects need to be of modest scope.
- Publication is mandatory; it places everyone's reputation on the line, including that of the students, instructors, schools, journals, and the seminar itself. Thus papers need to be of high quality. Writing, rewriting, and reviewing such papers takes time—typically half of the semester.
- Publication is not enough. Results should be presented by at least some of the students at conferences attended by researchers from the relevant community of practice.
- Team members should not be expected to contribute equally. Author order provides justice to variations, allowing each member to contribute as their time, talents, and experience dictate.
- Additional team members should be included from the outset or added, as needed or desired, from outside the class. Do whatever it takes to conduct and complete a high-quality research project.

## Past Cal Poly Student Engineering Development Projects

Scientific research in astronomy and other sciences often involves both scientists and engineers working together on projects; this was certainly my experience as a research supervisor at federal laboratories. Cal Poly has a large, renowned College of Engineering, and it was natural for me to tap student resources for advancing the development of small telescopes and associated instruments and software. For the past eight years I teamed up with Dr. John Ridgely in Mechanical Engineering to sponsor a series of senior projects and Masters Theses. Many of these projects were completed by student teams majoring in mechanical engineering, but there have also been electrical and architectural (structural) engineering student projects.

*Three mechanical engineering students pose with the "Cal Poly 18" alt-az telescope.*

Many of the same professional and amateur astronomers who supported the Cuesta College astronomy research students also supported the Cal Poly small-telescope engineering development students. This led to a fairly close, tight-knit community of practice that supported students at both of the two schools (which are only a few miles apart).

*Left: low cost, precision positioner for use in a hexapod telescope.*
*Right: a three-actuator telescope control system test setup.*

An early major project was the design and construction of an 18-inch alt-az telescope that pioneered the use of direct drives on smaller telescopes (no gears or pulleys—the telescope itself becomes the motor). The "Cal Poly 18" led directly to the CDK-700 28-inch telescope built by PlaneWave Instruments, now used by a number of major observatories around the world.

A three-student Cal Poly mechanical engineering team designed and built the prototype for an instrument rotator subsequently manufactured by Orion Telescopes. Another three-student team designed a low cost precision positioner for use in a hexapod platform that could contain medium-sized telescopes, while a Masters' student followed this with a control system for a telescope positioned by three screw mechanisms.

A three-student Cal Poly Architectural (structural) Engineering team designed and built a 1.5m light-bucket experimental telescope for high speed photometry and intensity interferometry. This portable telescope is a non-imaging flux collector.

*Left: The Cal Poly 1.5-meter experimental light-bucket flux collector telescope (the blue coating on the mirror protected the mirror during assembly). Right: installation of ultra-high-speed photometer for intensity interferometry field tests.*

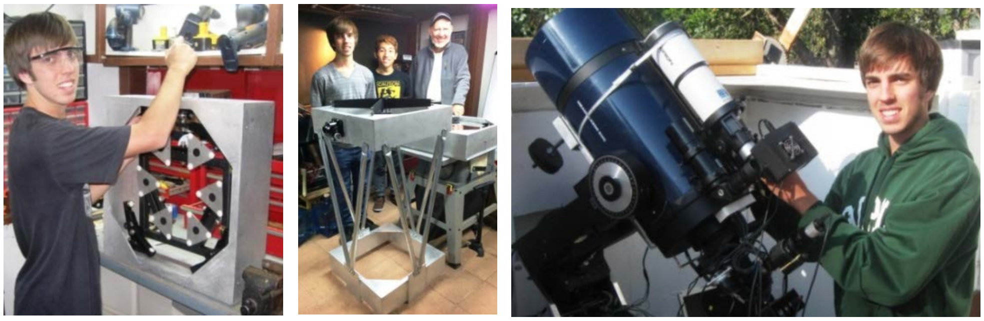
## Cal Poly Summer Research Seminar

For the past several years I thought it would be good to involve Cal Poly students in astronomical research and development during their first few years at college, not waiting until the senior year or graduate school to start conducting research. A key difficulty was that, during the school year, Cal Poly physics and engineering students are much too busy to devote time to a research seminar. Also, during the summer, when they do have time, they often need financial assistance if they are not to return home or forego some summer employment.

Thanks to the generosity of a private donor, Cal Poly was able to fund me and six undergraduate students—four physics students and two liberal studies (science teaching) students—for a six-week, in-person summer astronomical research seminar (2015). Another physics major, who lived locally, joined the seminar without funding.

*First three on left: Cal Poly students Donald Loveland, Kevin Phung, and Jennie Smit. First three on right (front to back), Zoe Sharp, Tristan Nibbe, and Jacob Hass. The students were presenting their proposed summer seminar research projects. Attending the briefing, left to right starting with yellow blouse, Drs. Lola Berber-Jimenez (Chair Liberal Studies Dept.), Phil Bailey (Dean College of Science and Mathematics), John Ridgely (Mechanical Engineering Department), Russell Genet (Research Scholar in Residence at Cal Poly and Cuesta College Instructor), and Jason Curtis (Dean of Science and Mathematics at Cuesta College). The photo was taken by Emily Hock (Liberal Studies student).*

Four of the physics majors were interested in telescope and instrument development. In response to this, two graduate mechanical engineering graduate students opened their engineering development projects to the physics students. This underscores a key point, and that is many scientists are instrumentalists, and there are many skills shared by both scientists and engineers, leading to a great deal of common ground for collaboration.



*Left: Jacob Hass installs a 17-point Wiffle-tree mirror suspension. Center: Hass, Keving Phung, and Genet and portions of the 17.5-inch optical tube assembly project. Right: Hass working on the intensified speckle interferometry project.*

The seminar students met with me on Tuesday, Wednesday, and Thursday mornings for six weeks. Teams were quickly formed, with most students being a member of more than one team. Each team prepared a written proposal and gave formal presentations on their proposals.

In one of the projects, seminar physics major Donald Loveland led a team that evaluated shaped aperture masks developed by Cal Poly ME graduate student Edward Foley in conjunction with a post-doc, Neil Zimmerman, at Princeton University working on similar masks for space telescopes. Shaped aperture masks preferentially diffract the bright light of the parent star away in specific directions, forming dark discovery zones to image faint exoplanets. We are employing masks for the same purpose to discover faint secondary stars in binary systems.

*A number of the seminar participants attended an Orion Observatory potluck dinner and observing session. Ed Foley, seated front and center, displays the shaped aperture mask he designed.*

The most ambitious project, completed by Matthew Clause, a Mechanical Engineering graduate student, was a three-mirror laboratory prototype for a sparse aperture speckle interferometry telescope. If a number of small spherical mirrors can be brought into phase via servomechanisms at low cost, they can form the basis of an inexpensive large telescope. Initial cost estimates suggest that a 4 meter sparse aperture telescope could be built for about \$500,000, about 1/100$^{th}$ the cost of a traditional filled aperture telescope of this size.

*Matthew Clause, a mechanical engineering graduate student, designed and built the nine high-precision actuators on the left that supported three spherical mirrors, center, all mounted in a test tower, right, with a high brightness LED and astronomical camera at the center of curvature to enable optical alignment through the use of interferometry.*

## The Seminar's Surprising Outcome

My original plan for the Cal Poly summer six week seminars was to form two teams, each with three students, to undertake a couple of very straight forward double star observational projects that could be completed, including observations, analysis, paper writing, and external review, within six weeks. The last day of the seminar would be set aside for formal briefings on their projects by the two teams. This is not what happened.

Instead of just moving ahead with this plan, I thought it might be interesting to lay out various projects that I was working on or thinking about, and that other (engineering) students were working on at Cal Poly. I was not totally surprised that a number of the physics students were keenly interested in being involved in a hardware project. Students wanted to know if they could work on more than one project. If the projects couldn't be finished in six weeks, they wondered, could they be continued in the second six weeks of the summer—much of it via the internet (which works for writing and polishing papers). Almost always willing to try something new (and seeing the chance for Cal Poly science and engineering students to work directly together on astronomy research and development projects), we went ahead with this highly ambitious approach to the summer research seminar.

With such a solid group of projects all related to double star research and development one way or the other, it seemed appropriate that the papers should be published as a special issue of the *Journal of Double Star Observations* and then reprinted as a hardcover book. However, editing a special issue of a journal and publishing a hardcover book are both major tasks, albeit tasks that can be valuable training for students and significant resume builders.

Anticipating this publishing opportunity, a parallel summer project, conducted with the seminar itself as the "guinea pig", was launched. The project developed a student paper format and instructions that allowed students themselves to bring their own papers into nearly publishable format. This development was spearheaded by a three-person team: Cal Poly Graphic Communication student Meghan Legg; long-time astronomy research seminar supporter, educator, and English expert Dr. Vera Wallen; and the Managing Editor of the Collins Foundation Press, Dr. Cheryl Genet. They developed a format and instructions, held a mini-workshop for the students on how to format their papers, and also provided the students with written instructions. The students, in turn, provided the team valuable feedback. The publication project team also coordinated their format with the Editors of the *Journal of Double Star Observations,* the intended book publisher, and book's printer.

Jacob Hass, the local "volunteer" physics student, not only participated in most of the projects, but, being local, kindly helped to wrap up many of the projects in the second six weeks. He then volunteered to be the Editor of the special issue of the *Journal of Double Star Observations* as well as the hardcover book by the Collins Educational Foundation. Final formatting of the papers and the many activities required to publish a book were taken on by Cal Poly Graphic Communication students and Associate Editors Meghan Legg, Hope Moseley, and Sabrina Smith.

## Social Learning within Communities of Practice

*Communities of Practice* is both the title of the seminal 1998 book by Etienne Wenger and a cornerstone concept in social learning theory. Scientific research, as with most other human endeavors, is carried out within a community of practice.

> Communities of practice are formed by people who engage in a process of collective learning in a shared domain of human endeavor: a tribe learning to survive, a band of artists seeking new forms of expression, a group of engineers working on similar problems, a clique of pupils defining their identity in the school, a network of surgeons exploring novel techniques, a gathering of first-time managers helping each other cope. In a nutshell: Communities of practice are groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly (Wenger 1998).

Social learning takes place in the process of becoming a member of a community that defines what competence means in a specific domain of expertise. As Wenger (1998) points out:

> Learning is a matter of engagement: it depends on opportunities to contribute actively to the practices of communities that we value and that value us, to integrate their enterprises into our understanding of the world, and to make creative use of their respective repertoires … Practice is a process of interactive learning [that] enables newcomers to insert themselves into existing communities. It is the learning of mature members and of their communities that invites the learning of newcomers.

The students in our seminar learned by developing actual proficiency in the practices of a community of scientists and engineers, and publishing their work in places where it can be accepted or rejected by experienced members of that community. The process of introducing students to a specific practice of that community (writing a scientific paper) is not simply a matter of teaching them a set of writing conventions that they then apply: it involves expert members of that community acting as gatekeepers to the dynamic practices of the community.

For students, learning R&D practice is not just learning a skill but developing a new identity, which Wenger (1998) describes as a core dimension of learning in a community of practice:

> Learners must be able to invest themselves in communities of practice in the process of approaching a subject matter. Unlike in a classroom, where everyone is learning the same thing, participants in a community of practice contribute in a variety of interdependent ways that become material for building an identity. What they learn is what allows them to contribute to the enterprise of the community and to engage with others around that enterprise … Learning [within a community of practice] transforms our identities: it transforms our ability to participate in the world by changing all at once who we are, our practices, and our communities.

Wenger (1998) identified the solution to a key educational paradox that is represented by my astronomy research seminars:

> If learning is a matter of identity, then identity is itself an educational resource. It can be brought to bear through relations of mutuality to address a paradox of learning: if one needs an identity of participation in order to learn, yet needs to learn in order to acquire an identity of participation, then there seems to be no way to start. Addressing this most fundamental paradox is what, in the last analysis, education is about. In the life-giving power of mutuality lies the miracle of parenthood, the essence of apprenticeship, the secret to the generational encounter, the key to the creation of connections across boundaries of practice: a frail bridge across the abyss, a light breach of the law, a small gift of underserved trust — it is almost a theorem of love that we can open our practices and communities to others (newcomers, outsiders), to invite them in our own identities of participation, let them be what they are not, and thus start what cannot be started.

## Acknowledgments

There were many contributors to the astronomy research and development seminar who I am pleased to acknowledge. Funding was provided by a Cal Poly donor. Lola Berber-Jimenez (Chair Liberal Studies Dept.) initiated the seminar with the support of Phil Bailey (Dean College of Science and Mathematics). John Ridgely (Mechanical Engineering Department) supported the seminar with his graduate students, Edward Foley and Matthew Clause.

David Rowe (CTO of PlaneWave Instruments) provided technical guidance on several projects and, along with John Kenney (Chair, Physics and Astronomy Dept., Concordia University) and Bruce Holenstein (President, Gravic Inc.) funded the three matched spherical mirrors for the sparse aperture telescope experiment. We thank Tong Lui (President, Hubble Optics) for making these mirrors. Reed Estrada (Chief Edwards Test Pilot, Northrop Aviation) and Chris Estrada (Univ. of California, Los Angeles), made the sparse aperture telescope test stand designed by Cal Poly Architectural Engineering student Michael Nidetz.

Benoit Schillings (Director, La Cresta Observatory) loaned us the optical intensifier used in one of our projects. Clif Ashcraft (Director, Perrineville Observatory) made the crucial observations for the paper on the ZWO CMOS camera. Joseph Carro (Cuesta College) provided the telescope (and its operation) for the student observations of Alberio, while Brian Mason (U.S. Naval Observatory) provided the past observations of Alberio. Richard Harshaw (Director, Brilliant Sky Observatory) was instrumental in our analysis of past speckle interferometry observations of close double stars at Kitt Peak National Observatory.

Cheryl Genet (Collins Foundation Press), Vera Wallen (retired Coast Union School District Superintendent), and Meghan Legg, Hope Moseley, and Sabrina Smith (Cal Poly Graphic Communication students) were instrumental in formatting and publishing the collected papers. Finally, and certainly not least, a very special thanks to Jacob Hass (Cal Poly Physics student) for editing this volume.

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