Student Research within Communities of Practice

Third Annual Report, NSF Grant #1610350, August 2019

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Accomplishments

What are the major goals of the project?

This grant, *Student Research within Communities of Practice: A Dynamic New Paradigm for Transforming Undergraduate Science Education,* has four major goals for expanding, extending, exploring, and evaluating the Astronomy Research Seminar:

- *Expand* the Seminar to many additional schools and instructors with a more fully developed supporting community of practice
- *Extend* the Seminar from double star astrometry to other areas of research within astronomy
- *Explore* the potential of extending the seminar beyond astronomy to environmental (atmospheric) science by way of a modest pilot project
- *Evaluate* the potential benefits of the seminar to its student graduates

Provided below is background information on the seminar that places these four major goals in context.

Original question

When the Seminar began in earnest a decade ago, the question was: "could undergraduate student teams complete modest scientific research projects within the confines of a single semester?" Furthermore, could they operate in the same way that professional research team do, including definition of a research objective, unequal contributions by team members, a paper submitted for publication and a public presentation of their research results? That this was indeed the case has now been amply demonstrated by more than 150 published papers from the Astronomy Research Seminar in its various forms with some 500 coauthors.

Each student seminar team

- Writes a research proposal and submits it for approval
- Manages their own research (with supervision, as is the case with most professional research teams)
- Obtains and analyzes original data
- Writes a team paper
- Obtains external review of their paper
- Submits their paper for publication to an appropriate community of practice journal
- Gives a public PowerPoint presentation or presents their results in a poster

To make this possible

- Student teams conduct research within an established, professional-amateur (pro-am) community of practice
- The teams conduct their research in a single topic area selected to facilitate timely paper submission
- Nearly total focus is on producing a high quality published research paper
- Their research is supervised (but not led or managed) by an instructor
- The students are supported by experienced researchers, who can include professionals, amateurs, and former seminar students, all drawn from the relevant community-of-practice

Potential student benefits

- By conducting complete research projects as members of an established community of practice—including being a coauthor of a published paper—students may come to identify themselves as scientists. This identity could provide them with the *grit* many may need to complete their educational objectives. In psychology, *grit* is referred to as a positive, non-cognitive trait based on an individual's passion for a particular long-term goal or end-state, coupled with a powerful motivation to achieve their respective objective.
- Being a coauthor of a research paper could improve a student's chance of admission to their school of choice with a scholarship, thanks to their undergraduate research experience
- Completing a team research project should provide students with useful, transferable skills in team participation and leadership, project planning and management, data acquisition and analysis, technical writing and critical thinking, and presenting research results in public.

Cooperative Seminar development and evaluation program goals

For many years, the seminar was conducted in person once a year (8 weeks every fall) at a single school (Cuesta College) and by a single instructor (Genet). In 2015, the Seminar began expanding to new locations, most notably in the San Diego area where Pat and Grady Boyce, under the auspices of the Boyce Research Initiatives and Education Foundation (BRIEF), taught the Seminar at a number of high schools. Instructors at three San Diego community colleges then started teaching the Seminar.

The various instructors, schools, and their many supporters have formed a cooperative Seminar development community, the Institute for Student Astronomical Research (InStAR). Four community members—California Polytechnic State University, the Council on Undergraduate Research, the Collins Educational Foundation, and Concordia University Irvine—requested assistance from NSF (which was granted).

Summary of the project's goals

- *Expand* the Seminar to other schools and instructors
- *Extend* the Seminar to other research areas within astronomy
- *Explore* the extension of the Seminar beyond astronomy
- *Evaluate* the Seminar's potential student benefits

What was accomplished under these goals?

Major Activities

The four major activities in the project's third year remained the same as the first two years and were directly related to the project's four goals. Details on these activities are provided below in the section on *Significant Results*. These activities were:

- Expanding the seminar in an economical manner to other schools and instructors with a more fully developed supporting community of practice

- Extending the seminar in an economical manner to other areas of research within astronomy
- Exploring the potential of extending the seminar beyond astronomy to environmental (atmospheric) science by way of a modest pilot project
- Evaluating the potential benefits of the seminar to its student graduates

Specific Objectives

The four specific objectives remained the same in the third year of the project as in the first two years and matched the four goals of the project. These objectives:

- *Expand* the Seminar to other schools and instructors
- *Extend* the Seminar to other research areas within astronomy
- *Explore* the extension of the Seminar beyond astronomy
- *Evaluate* the Seminar's potential student benefits

Significant Results

***Expand* the Seminar to other schools and instructors**

American Association for Physics Teachers (AAPT) – January 2019, Houston, TX

A four-hour workshop was given by Rachel Freed, InStAR President, in Houston, Texas at the Winter Meeting of the AAPT with 14 attendees who were College Instructors from institutions around the country. During the workshop, the participants were walked through most of the process of conducting the research seminar.

Lick Observatory – March 31, 2019

An all-day workshop was provided at Lick Observatory on March 31st. The workshop was provided by Rachel Freed, InStAR President, with assistance from Kalee Tock from Stanford High School (OHS). The same general workshop protocol was followed as had been followed at the AAPT Winter Meeting, but with breaks for the observatory tour and talk.

Northeast AstroImaging Conference (NEAIC) – April 5, 2019

Suffern New York

Rachel Freed provided a four-hour workshop at NEAIC, with the goal of teaching local astronomy educators, amateur astronomers, and students about the astronomy research seminar and how to use the tools for data collection and image analysis. Additionally, it was a forum in which student researchers who had done the seminar could present their work. Because Stanford Online High School has students all around the country and the world, there were a few who live in the northeast United States who took

Mount Wilson Observatory – May 2019

In May of 2019, a Double Star Workshop was held at Mount Wilson Observatory in Southern California. Groups of students from three different institutions participated in the workshop: 12 students from Stanford University Online High School (OHS), three students from the Boyce Research Initiative Educational Foundation (B.R.I.E.F), led by a former student in the program who now serves as a mentor

for numerous student groups, and ten students from the Lewis Science Center. Of these 10 students, 9 had originally participated in the astronomy research seminar in 2015 or 2016 as 8th graders, and several of them had continued on to do two or three projects and papers over the next few years before attending this workshop five years after their introduction to the seminar. This speaks highly to the potential of the astronomy research seminar steer students towards studying STEM beyond their initial introduction.

Society for Astronomical Sciences (SAS) – June 2, 2019, Ontario, California

A half-day workshop was provided following the Society for Astronomical Sciences Annual Symposium with the aim of bringing together the advanced amateur astronomers in the organization who conduct and publish their research, with educators and students, to further build the Community-of-Practice, promote intergenerational-learning, and provide a forum for the students to present their research to an authentic audience, one that is doing the same type of research as the students and who would be interested in and could be informed by their work. Seven students from OHS attended the SAS Symposium and talked with the SAS members and astronomy equipment vendors. Five of them then presented a 2-minute "sparkler talk" about their posters and presentations. Five students presented their research in 10-minute talks at the workshop following the symposium.

Mount Wilson Speckle Interferometry Workshop – June 11-13, 2019

Eight Paso Roble High Schools Students went through the Astronomy Research Seminar in the Spring of 2019 with their instructor, Jon-Paul Ewing. The Paso Robles High School teams consisted of 8 students (7 females and 1 male) who utilized this set-up, with assistance from the engineering team, to collect 4000 images, 1000 each with four different filters, on four stars selected for study.

AAPT Summer Meeting workshop July, 2019

A 4-hour workshop was held at the 2019 American Association of Physics Teachers conference in Provo,

Extend the Seminar to other research areas within astronomy

Several Exoplanet Light Curve papers are in preparation, and a course on using Speckle Interferometry to measure close doubles is being developed.

Considerable progress was made during the third year of the grant with respect to extending, in the future, the Seminar observations to small CubeSat space telescopes. Genet organized a one-day *CubeSat Astronomy* workshop at California Polytechnic State University in April (2019) that was attended by folks from NASA HQ, JPL, MIT, etc. Another workshop was held (for the second year) in Portland (Oregon) as part of the 12th Annual Alt-Az Initiative meeting. A one-day *CubeSat Astronomy in the 2020s* workshop was approved as part of the American Astronomical Society's annual winter meeting in Honolulu, January 4, 2020. Finally, Genet was first author on a white paper, *CubeSat Astronomical Telescopes and Research in the 2020s,* that was submitted to the National Academies Astro 2020 Decadal Study.

***Explore* the extension of the Seminar beyond astronomy**

Two extensive discussions were held during mini-workshops at Southern Utah University with Jacqueline Grant in the second year of the grant. Grant is proceeding to initiate student-team research seminars in the areas of biology and geology within the national parks. A proposal for NSF support has been prepared and will be submitted shortly.

Another extension of the seminar beyond astronomy is being explored. The exploration of this extension has just started. A no-cost extension of the grant to a fourth year was requested and approved. The description of this effort is provided below in the section, *What do you plan to do during the next reporting period to accomplish the goals?*

***Evaluate* the Seminar's potential student benefits**

The astronomy research seminar and similar programs have had significant impacts on students' lives and career choices leading many towards STEM fields. Rachel Freed is evaluating these projects and their impacts as more and more seminars begin. She is also beginning to evaluate the impacts on educators who go through the astronomy research seminar to see if there are sustained changes in pedagogical approaches to teaching as well as changes in self-efficacy relating to teaching students how to conduct research. She has created and piloted an instrument to test the Self-Efficacy around robotic telescope use in education as well as an instrument around self-efficacy of teaching research. In the pilot of over 350 college students in astronomy classes at the University of North Carolina, Chapel Hill, a brief use of remote robotic telescopes had a significant impact on self-efficacy raising the mean scores on the instrument from 22 to 39 with just two weeks of exposure to the remote telescope system. This work will be continued over the next few years.

Other studies underway include interviews with students who have remained involved with astronomical research since their introduction to the seminar as 8th graders five years ago and this past summer conducted research at Mount Wilson Observatory using the 100" Hooker Telescope. These results will eventually be submitted for publication.

Key outcomes or other achievements

As stated in the first annual report and repeated here for emphasis, the principal achievement of the Seminar every year has always been and will continue to be the student team's published papers. The firm requirement that each student team's research end with a paper submitted for publication is the hallmark of the Seminar.

To a considerable extent, the Seminar can and should primarily be judged on three things: (1) the quality (and quantity) of its published papers, (2) the impact that being a co-author of a published research paper has on the Seminar's students in terms of their perception of being a scientist, and (3) the effect that publication has on their educational careers.

In the third year of the grant, 27 student team papers were published in the *Journal of Double Star Observations* as listed below, and there are currently about 15 more in preparation for submission. These papers have students from over 10 institutions, mainly community colleges and high schools.

Volume 14, No 4, October 2018
Student Team Paper Astrometric Measurements of WDS 00198+7518 (HJ 1950) and WDS 01373+6344 (MLB 383AD)
Coauthors Leilani Trautman, Donald Sheahan, Justin Perng, John Gooding, Robert Zarick, Sébastien Cormier, and Philip Blanco
Publication *JDSO* Vol 14, No 4, page 648, October 2018

Student Team Paper Comparison and CCD Measurements of Four Double Star Systems: WDS 03003+1432, 03009+5221, 03001+3911, 08165+7930
Coauthors Jack Cahill, Zoe Boysen, Mac Clark, Grace Wagner, Kalée Tock
Publication *JDSO* Vol 14, No 4, page 694, October 2018

Student Team Paper WDS 00049+3005 STT 548AC, Ignored for 156 years?
Coauthors Lucy Conover, Saskia Onggo, Savannah Pluma, Bryce Belshin, Brian Delgado, Pat Boyce, and Grady Boyce
Publication *JDSO* Vol 14, No 4, page 707, October 2018

Student Team Paper CCD Astrometric Measurements of WDS 04346-7015 GL 203 AB
Coauthors Jeremy Ha, Alex Falatoun, Shannon Detwiler, Sean Gillette, Pat Boyce, and Grady Boyce
Publication *JDSO* Vol 14, No 4, page 728, October 2018

Student Team Paper Astrometry of STF 1985 Shows Continued Off-Orbit Path
Coauthors Beckett Andersen, Jon-Paul Ewing, Adrian Griffin, Beatriz Lopez, Kate Reupold, Katherine Pham, Rachel Freed, Richard Harshaw, and Russell Genet
Publication *JDSO* Vol 14, No 4, page 731, October 2018

Volume 15, No 1, January 2019
Student Team Paper Astrometric Measurements of WDS 14039-6219 (R 230)
Coauthors Francesca D'Amico, Cassidy Sullivan, Grady Boyce, and Pat Boyce
Publication *JDSO* Vol 15, No 1, page 17, January 2019

Student Team Paper WDS 09144+5241: CCD Observations and Orbital Solutions
Coauthors Chance Crigler, Beatrice Millar, and Hagan Hensley
Publication *JDSO* Vol 15, No 1, page 108, January 2019

Student Team Paper CCD Measurements and Reclassification of WDS 07106 +1543 to an Optical Double
Coauthors Owen Dugan, Thomas Robinson, Finnian Carmeci, and Kalée Tock
Publication *JDSO* Vol 15, No 1, page 119, January 2019

Student Team Paper Astrometric Measurements of 118 Year Neglected Double Star System WDS 15229-2910
Coauthors Cloe Moreno, Aaron Price, William Harris, Scarlett Steiner, Brian Delgado, Pat Boyce, and Grady Boyce
Publication *JDSO* Vol 15, No 1, page 174, January 2019

Student Team Paper CCD Astrometry of the Host star system HD 75289 with Exoplanet
Coauthors Charize C. Balignasay, Jocelynn F. Bolosan, Vea Aubrey Bumatay, Pink Mariz G. Felipe, Jeffrey Friedman, Shanti C. Mohanan, Donald C. Napala, Skecynyth H. Perlas, Vanessa Rhea C. Sao, Evan Sugayama, Lea Stuart, Sierra Ryden, Yasmina Vafaie, Mark Silliman, Brandi Giese, Kakkala Mohanan, Diana Castaneda, James D. Armstrong, and Russell Genet
Publication *JDSO* Vol 15, No 1, page 184, January 2019

Student Team Paper CCD Measurements of AB and AC Components of WDS 20023+6438
Coauthors William Zerkle, Dallas Anselmo, Taylor Hammack Gideon Johnson, Morgan Taylor, Sterling Young, and Rhett Zollinger
Publication *JDSO* Vol 15, No 1, page 203, January 2019

Volume 15, No 2, April 2019
Student Team Paper Astrometry of STF 1510

Coauthors Elizabeth Phillips, Morgan Harrington, Monica Rodriguez, Jiseelle Jimenez, Mandy Lee, Paulina Mondragon Lopez, Leslie Ramirez, Laura Santos, Jon-Paul Ewing, Rachel Freed, and Russell Genet
Publication *JDSO* Vol 15, No 2, page 210, April 2019

Student Team Paper CCD Astrometric Measurements of WDS 12001+7039
Coauthors Hannah Blythe, Bella Morales, Tatianna Steiner, Marco Sanchez, Pat Boyce, and Grady Boyce
Publication *JDSO* Vol 15, No 3, page 213, April 2019

Student Team Paper An Astrometric Measurement of WDS 16476-4708 AB and AC
Coauthors Kelcey Davis, Sophia Vanslyke, Pat Boyce, Grady Boyce, and Ashlyn Little
Publication *JDSO* Vol 15, No 3, page 217, April 2019

Student Team Paper Astrometric Measurement and Analysis of Celestial Motion for Double Star WDS 10494+5517
Coauthors Theophilus Human, Seeraj Somla, Angel Ha, Jae Calanog, Grady Boyce, and Pat Boyce
Publication *JDSO* Vol 15, No 3, page 221, April 2019

Student Team Paper Measurements of Star System 00345-0433 STF 39AB,C
Coauthors Amanda Tran, Audrey Lee, Samuel O'Neill, Abigail Wu, and Allen Priest
Publication *JDSO* Vol 15, No 3, page 225, April 2019

Student Team Paper CCD and GAIA Observations Indicate That WDS 02222+2437 Is Not Gravitationally Bound
Coauthors Hamza Samha, Jonathan Ginouves, Taime Clark, Savana LeBaron, Jasmine Tapia, Micah Jackson, and Cameron Pace
Publication *JDSO* Vol 15, No 3, page 228, April 2019

Student Team Paper Measurement of Star System 00304-0947 CHE 27
Coauthors Amanda Tran, Audrey Lee, Samuel O'Neill, Abigail Wu, and Allen Priest
Publication *JDSO* Vol 15, No 3, page 232, April 2019

Student Team Paper Astrometric Measurements of WDS 04136-2532
Coauthors Vivek Vijayakumar, Curran Poulsen, Alex Falatoun, Pat Boyce, and Grady Boyce
Publication *JDSO* Vol 15, No 3, page 235, April 2019

Student Team Paper Measurement of Star System 02442+4914 STF 296AB
Coauthors Amanda Tran, Audrey Lee, Samuel O'Neill, Abigail Wu, and Allen Priest
Publication *JDSO* Vol 15, No 3, page 239, April 2019

Student Team Paper Astrometry Observations of Six Uncertain Double Stars
Coauthors Cooper Howlett, Erin Pickering, Joshua Breman, Malia Barker
Publication *JDSO* Vol 15, No 3, page 248, April 2019

Student Team Paper Astrometric Measurements of WDS 13169+1701 Binary Star System in Coma Berenices
Coauthors Shannon Pangalos-Scott, Danielle Holden, Melody Fyre, Zach Medici, Jaeho Lee, Micaiah Doughty, Rebecca Chamberlain, Rachel Freed, and Russ Genet
Publication *JDSO* Vol 15, No 3, page 255, April 2019

Student Team Paper Astrometric Measurements of Double Stars HJ 4194 and HJ 4195
Coauthors Vincent Aguilar, Emmanuel Mercado, Hugh Le, Tianlin Zhao, Jae Calanog, Grady Boyce, and Pat Boyce
Publication *JDSO* Vol 15, No 3, page 260, April 2019

Student Team Paper Measurements of the Position Angles and Separations of the Double Stars WDS 16579+4722 AB and AC components
Coauthors Nathan Sharon, Renae Bishop, Cole Rodgers, Sophia Baer, Rachel Freed, Cheryl Genet, and Russell Genet
Publication *JDSO* Vol 15, No 3, page 297, April 2019

Volume 15, No 3, July 2019
Student Team Paper Astrometric Measurements of Star System WDS 06571+5438
Coauthors Alex Hewett, Mikila Tuchscher, Marie Yokers, Alexander Beltzer-Sweeney, Irena Stojimirovic, Pat Boyce, and Grady Boyce
Publication *JDSO* Vol 15, No 3, page 332, July 2019

Student Paper The Human Element: Why Robotic Telescope Networks are not always Better, and Performing Backyard Research
Author Ryan Caputo
Publication *JDSO* Vol 15, No 3, page 408, July 2019

Student Team Paper Near Infrared Robotic Observation of Double Star System WDS 13513-3928
Coauthors Stephen White, James Gallegos, Grady Boyce, Pat Boyce, and Carson Barnett
Publication *JDSO* Vol 15, No 3, page 429, July 2019

What opportunities for training and professional development has the project provided?

There have been about 10 workshops provided around the United States to inform educators about the Astronomy Research Seminar as well as train them in the tools and pedagogical approaches of the Seminar. The Seminar is being provided in September/ October 2019 for dozens of college and high school instructors around the country who were at the conferences and workshops where the seminar was discussed. Sixty-two Instructors have been invited to participate and encouraged to have their students join as well.

How have the results been disseminated to communities of interest?

Results during the third year of the grant were disseminated similarly as before via talks at conferences and meetings, including the American Association of Physics Teachers (AAPT) Winter and Summer meetings, the Society for Astronomical Sciences, the Council on Undergraduate Research's Undergraduate Research Programs conference, the North East Astronomy Forum in New York, the Texas Star Party, the California Math and Science Teacher Initiative (MSTI) Director's Convening, the "Building the NASA Citizen Science Community" workshop and others.

What do you plan to do during the next reporting period to accomplish the goals?

A new Seminar with a topic beyond astronomy will be explored. The Seminar's local team projects will be small subsets of the larger question: "Will our rapidly expanding technology and population result in a sudden crash, or will we take the unprecedented evolutionary step of consciously managing our dynamically unstable situation?"

This new Seminar will provide an introduction to dynamic models of humanity (with mathematical side-bars) that describes Lotka-Volterra models of early hunter-gatherers, farming communities, agrarian civilizations, and runaway technical civilizations (simulation results for each case and instructions for readers optionally running their own simulations). Related models of socio-political dynamics, and economic growth are also presented. Linked, total-system dynamic models of humanity and climate could provide guidance for adaptively managing our future evolution trajectory.

Besides understanding the larger dynamic picture, student teams will choose some local aspect of the problem to model, write up their simulation results for publication, and give them as a talk at a workshop or conference.

Modest funding for this project is also being provided by the Cultural Evolution Society.

Supporting Files

CCD and GAIA Observations Indicate That WDS 02222+2437 Is Not Gravitationally Bound	Hamza Samha, Jonathan Ginouves, Taime Clark, Savana LeBaron, Jasmine Tapia, Micah Jackson, and Cameron Pace
CCD Measurements and Reclassification of WDS 07106 +1543 to an Optical Double	Owen Dugan, Thomas Robinson, Finnian Carmeci, and Kalée Tock
Astrometry of STF 1985 Shows Continued Off-Orbit Path	Beckett Andersen, Jon-Paul Ewing, Adrian Griffin, Beatriz Lopez, Kate Reupold, Katherine Pham, Rachel Freed, Richard Harshaw, and Russell Genet
Astrometric Measurements of WDS 04136-2532	Vivek Vijayakumar, Curran Poulsen, Alex Falatoun, Pat Boyce, and Grady Boyce

Products

Conference Papers

Evaluation of the Astronomy Research Seminar
Accepted for publication in the Robotic Telescopes, Student Research and Education (RTSRE) Proceedings 2019
Rachel Freed

Astronomy Research Seminar Expansion and Building a Community-of-Practice
Accepted for publication in the Robotic Telescopes, Student Research and Education (RTSRE) Proceedings 2019
Rachel Freed

Development and Validation of an Astronomy Self-Efficacy Instrument
In Preparation for publication
Rachel Freed, Michael Fitzgerald, Annette Nykiel, David McKinnon

Website

Institute for Student Astronomical Research
www.In4StAR.org
The Institute for Student Astronomical Research (InStAR) was established in the grant's first year to develop and expand the student-centered community of practice that supports the Astronomy Research Seminar. InStAR's website at In4StAR.org provides information about the Seminar, useful information for students and instructors to download, announces workshops and conferences, and recognizes the contributions of students, instructors, and Seminar supporters. During the third year of the grant, the Institute significantly upgraded and expanded its website.

Other Products

Education aids or curriculum
A complete Course has been created for the astronomy research seminar and is freely through Canvas Commons for anyone to use and adapt to their needs. It consists of eight units, each complete with the detailed assignments, links to videos, reading material, and quizzes and tests. It has been designed to make it as easy as possible to be updated every time the course is taught. For example, it is highlighted for educators where they need to change the due dates for assignments. The materials match the *Small Telescope Astronomical Research Handbook* that was published as a resource for the course as well as for any astronomers, professional or amateur, interested in getting into this sort of work. YouTube videos are continually created to help people easily implement new software or processes that are developed in the every-evolving fields of research and technology.

Instruments or equipment
The Seminar aims for the published research by its student teams to have both high educational and scientific value. A supportive, voluntary community of professional astronomers and professional engineers (many of whom are also amateur astronomers) has been working to develop low cost (or free), easily used, student-friendly instrumentation and software for use by Seminar students and others. In double star astrometry—the primary area of Seminar research for many years—the scientific value of observations tends to increase as the apparent (angular) separation between the two stars decreases. The most valuable observations tend to be below the seeing limit, requiring advanced techniques such as speckle interferometry with very expensive electron multiplying CCD (emCCD) cameras and specialized reduction software. During the third year of the grant, the $400 CMOS camera (that uses a back-illuminated chip recently developed by Sony) was used more extensively, including for observing runs on the 100-inch telescope on Mt. Wilson. This development allows student teams to conduct research at the very forefront of double star astrometry. PI Genet, with technical help and contributions from David Rowe and Dan Gray, is working to fully automate speckle interferometry at his observatory. During the third year of the grant a robotic telescope was designed, and construction has begun by students at the machine shop at the California Polytechnic State University.

Evaluation of the Astronomy Research Seminar	Rachel Freed
CubeSat Astronomical Telescopes and Research in the 2020s	Russell Genet, Jonathan Arenberg, Howard Banich and 29 other coauthors
Astronomy Research Seminar Expansion and Building a Community-of-Practice	Rachel Freed

Development and Validation of an Astronomy Self-Efficacy Instrument In Preparation for publication	Rachel Freed, Michael Fitzgerald, Annette Nykiel, David McKinnon

Other Participants

Philip Blanko, Grossmont College, San Diego, CA
Grady Boyce, Boyce Research Initiatives and Education Foundation, San Diego, CA
Pat Boyce, Boyce Research Initiatives and Education Foundation, San Diego, CA
Robert Buchheim, Society for Astronomical Sciences, Ontario, CA
Jae Calanog, Miramar College, San Diego, CA
Rebecca Chamberlin, The Evergreen State College, Olympia, WA
Dennis Conti, American Association of Variable Star Observers, Annapolis, MD
Sebastien Cormier, Grossmont College, San Diego, CA
Michael Fitzgerald, Edith Cowen University, Perth, Australia
Chris Estrada, California State University, Los Angeles, CA
Reed Estrada, Northrop Aviation, Lancaster, CA
Richard Harshaw, Brilliant Sky Observatory, Cave Creek, AZ
Jolyon Johnson, Sammamish High School, Belleview, WA
Tom Meneghini, Mount Wilson Observatory, CA
Kakkala Mohanan, Leeward Community College, Pearl City, Oahu, HI
Peter Richerson, University of California, Davis
David Rowe, PlaneWave Instruments, Rancho Dominguez, CA
Mark Silliman, Waipaha High School, Waipaha, Oahu, HI
Irena Stojimirovic, Mesa College, San Diego, CA
Kalée Tock, Stanford Online High School, Palo Alto, CA

Impact

What is the impact on the development of the principal discipline(s) of the project?

The impacts remain primarily the same as in the first and second years of the grant but have been updated as appropriate below.

Undergraduate student science education

The Astronomy Research Seminar, enhanced and expanded by this NSF-funded project, is demonstrating that a large number of teams of undergraduate students can plan and complete published astronomical research projects in a single semester or less on a regular basis. While the Seminar draws on such pedagogical methods as team-based learning, project-based learning, and experiential learning, the primary contribution of this project to advancing science education is in applying social learning theory—specifically communities-of-practice theory—to science education. Seminar students are immersed within a supportive community of practice. The pioneering founder of the community-of-practice theory, Etienne Wenger is a project consultant (please reference his 1998 book, *Communities of Practice: Learning Meaning, and Identity,* which launched the field).

Double star astrometry research

Our knowledge of the relative motions of double stars has been built up over the past two centuries by many hundreds of observers publishing the position angles and separations of some 130,000 known

double stars, of which about 3000 are gravitationally bound binary stars. Keeping tabs on all these stars is beyond the capabilities of professional astronomers, so published observations, made by all observers, including amateur astronomer and Seminar students, are summarized in the Washington Double Star Catalog (maintained by the U.S. Naval Observatory) for the benefit of the entire double star research community. Published student research advances science in this specialized area of research. As student teams increasingly use speckle interferometry for their observations, the scientific value of their contributions to the advancement of science will increase.

What is the impact on other disciplines?

While the Seminar is currently aimed primarily at undergraduate students, and hence improving undergraduate science education, the Seminar has also been taken by many high school students. Could the benefits of early research, already shown to be effective for undergraduate students, be extended by research seminars to an even earlier age in a systematic manner? The Seminar has been successfully completed by a number of eighth grade students in a middle school, although it was an unusually opportune set of circumstances that allowed this to happen.

What is the impact on the development of human resources?

Undergraduate student research

It has been well established that involving students in research while they are undergraduates helps launch then on productive careers in scientific research or engineering development. The NSF's program of Research Experiences for Undergraduates (REU) is a highly successful example of such research. The NSF-funded expansion and extension of the Astronomy Research Seminar aims to make published undergraduate student research possible on a national scale by providing a highly economical (just a few hundred dollars per student), fully online, research experience that can be completed in one semester or less. The self-supporting nature of the Seminar and the relative speed with which it is being adopted by other schools, as well as the large number of published papers, bodes well for the potential of national expansion.

Science teaching

While, as its name suggests, the Astronomy Research Seminar has been devoted to student-team astronomical research, it seems likely that the Seminar's pedagogical model—student team research within a supportive community of practice—may be applicable to other areas of science (or even beyond science). To investigate this possibility, this grant applied the Seminar's model to environmental science, specifically atmospheric science. While not part of this project, the application of the Seminar's community of practice model to aviation education is also being investigated.

Public participation

Compared to normal school classrooms or laboratories, which understandably work to protect students from contact with anyone who is not an instructor or fully authorized and vetted assistant or registered student, the Seminar encourages and in fact *requires* contact with outside-the-school professional and amateur astronomers, former students, or anyone who can help the student teams conduct their research and produce high quality published papers. This includes external expert referees who review student papers prior to their submission for publication. The research teams often include non-student members who work right alongside the students, providing them with support and expertise. Following the normal rules of science, all those who make significant contributions to the research project (not just the students) are included as coauthors of the published papers. The result is that the Seminar and its

published papers have a strong element of public participation. This benefits both the students and the public.

The Seminar has come to the attention of NASA as a vehicle for involving citizen scientists in published research. NASA is funding a national two-day workshop that will feature how-to instruction on publishable research projects in the areas of time-series photometry of asteroids and exoplanets, and solar astronomy. The Institute for Student Astronomical Research and the Planetary Science Institute will be the primary organizers of the workshop.

What is the impact on physical resources that form infrastructure?

The project is enhancing low-cost easy access to remotely-located robotic telescopes. The Seminar is pushing the state-of-the-art of robotic telescopes and observatories thanks to its requirement for access by many students at an increasing number of schools to robotic telescopes at low or no cost to them in a manner that is easily understood and implemented by the students. It was encouraging that, in the second year of the grant, Las Cumbres Observatory made its global network of telescopes available to Seminar student teams at no cost.

What is the impact on institutional resources that form infrastructure?

Having students participate in a community of practice that extends well beyond the school can help to reduce the often-mandated insularity of many schools of higher education—especially community colleges.

Making astronomical observations of high quality with advanced, cutting-edge instrumentation requires having many schools share robotic observatories located at remote, good-weather sites. Even for professional astronomers, such sharing of remote facilities is becoming the norm for 21st century research. The Seminar encourages such sharing and is developing the means to facilitate sharing.

What is the impact on information resources that form infrastructure?

To facilitate sharing of resources and avoid duplicative development of resources, the Seminar relies on and continues to develop the Institute for Student Astronomical Research (InStAR). InStAR provides an across-schools supporting infrastructure for the Seminar.

What is the impact on technology transfer?

The Seminar's requirement that instrumentation be low cost yet cutting-edge (from a research point-of-view) has resulted in several important developments by the Seminar's supportive instrumentation and software community. Perhaps most noteworthy is the spark provided several years ago by two undergraduate engineering student teams at California Polytechnic State University (Cal Poly SLO). They designed and built a small (18-inch aperture) pioneering low cost, direct-drive alt-az telescope that was patterned after large, many million-dollar mountaintop telescopes. The innovative *Cal Poly 18* telescope led directly to the PlaneWave Instruments' production of the CDK-700 0.7m research telescopes, of which 50 have now been built. These telescopes are primarily used by professional astronomers in various research projects requiring highly reliable and capable medium-aperture robotic telescopes. This is a case of *reverse* technology transfer, from students and amateurs to professionals.

The community that made this and several other reverse technology transfers possible was the Alt-Az Initiative (which has worked closely with the Astronomical Research Seminar community). The Alt-Az Initiative is composed of professional and amateur astronomers and engineers that meet in person every year in Portland, Oregon, and correspond frequently between these meetings. The members of the Alt-

Az Initiative have, from the beginning (over a decade ago), responded to the needs of the Seminar, and have offered technical support to the Seminar's students and instructors.

At this year's Alt-Az Initiative workshop, two Cal Poly students (Alex Johnson and Charles Van Steenwyk) presented their initial conceptual analysis of a Student Space Telescope Network (SSTN). The transfer of technology used on larger space telescopes is being considered for use on these small (20 cm) telescopes that will be placed in 12U CubeSats.

What is the impact on society beyond science and technology?

Because there are no prerequisites for the seminar, and it is stressed (as with professional science projects) that equal participation is not expected or even desired, each student contributes as their time, talents, knowledge, and experience dictate. This encourages *all* students to participate in a genuine research experience, completing the seminar as published scientists. While many of the students will eventually become professional research scientists or developmental engineers, others will, as science-informed citizens in an increasingly complex society, be able to more fully contribute to increasing our nation's economic competitiveness and discovering innovative solutions to the many problems we face as a global community.