How to Run a Successful Research Experience for Undergraduates (REU) Site

M. Grant Norton, David F. Bahr

School of Mechanical and Materials Engineering
Washington State University Pullman WA 99164-2920

Introduction

The Research Experience for Undergraduates (REU) site program supports active research participation by undergraduate students in any of the areas of research funded by the National Science Foundation (NSF). One of the goals of the program is that students are "involved in meaningful ways in ongoing research programs or in research projects specially designed for the purpose" [1].

For the past five summers the NSF has funded a summer REU site in Characterization of Advanced Materials at Washington State University. WSU currently has the longest active REU program in materials research in the northwest. Our REU site brings students to Pullman to spend 10 weeks each summer focused on interdisciplinary materials research.
The initial target population for our REU program was primarily students from schools in the Pacific Northwest and Rocky Mountain states that do not have access to the modern instrumentation that is needed for materials research. Over the five years of our program the number and popularity of REU programs has increased nationally and we have attracted students from throughout the United States as shown in Figure 1. To date a total of 55 undergraduates from 25 Universities in 9 majors have participated in on-going research programs in materials science working closely with faculty members and graduate students often in an interdisciplinary environment.

This paper describes our experiences in running an REU site. It describes what worked for us and what did not and the outcomes to date of our program. There are many REU sites around the country and some of these may be run along similar lines and have had similar successes.

Program Structure

Students apply to our REU site through an on-line application form and are required to submit one letter of recommendation and a brief statement of purpose. The application deadline is typically March 1. Selection is based on several criteria. In addition to making sure the applicant has an interest in the research activities being offered, we also seek to ensure a diverse group of participants in terms of academic background (freshman, sophomore, junior, and senior),

geographical location, and the participation of groups underrepresented in engineering and the physical sciences. However, the last requirement has not been used as a deciding factor in selection. Instead we have targeted recruiting directly at institutions, majors, and organizations, which result in an application pool that is more representative of the general population than the average demographic pool in engineering at Washington State University.

Our REU program starts at the beginning of June and runs for ten weeks ending the first week of August. We have found that interactions between the students are increased if they all stay in dormitory accommodation on campus. These interactions are important not only on the social level but also appear to increase collaborations in the laboratory. During the first week of the program the students meet each other, are introduced to the faculty participants, have a tour of campus, and begin their research programs. We have developed a 1-credit course specifically for the REU program that introduces students to the various characterization methods they may encounter in materials research. The course is structured in a series of afternoon modules that include laboratory sections in techniques such as scanning and transmission electron microscopy, atomic force microscopy, and nanoindentation methods for measuring surface mechanical properties.

During the program we organize trips to a local company that utilizes electron microscopy for failure analysis in electronic devices and to the Environmental Molecular Sciences Laboratory (EMSL) at the Pacific Northwest National Laboratory in Richland, WA. The EMSL facility has a suite of state-of-the-art characterization equipment. The students take samples from their own research and get them analyzed at EMSL using techniques such as X-ray photoelectron spectroscopy and Auger electron spectroscopy.

At the end of the summer the REU participants prepare a poster on their research. Many of the materials faculty, graduate students and also some senior level administrators at the university attend the poster sessions. The posters are then placed on our REU web site. [2]

Recruiting

Recruiting high quality undergraduates into an REU program is essential for the overall success of the program. The primary sources that undergraduates use to obtain information about REU sites are:

- NSF web page
- Other students
- Faculty
- Contacting student groups directly

The most effective method appears to be recommendations from other students. Of the 25 universities from which we have drawn students nine of those institutions have provided students in at least two years. The anecdotal evidence is that positive recommendation from previous program participants is a significant factor in determining where new students choose to apply. Faculty recommendations are clearly important and over the years we have sought to make connections with specific faculty at various institutions to ensure that we can have student applications from those schools. In terms of the least effective methods of recruiting, contacting individual campus student groups (SWE, ASME, NSBE) through email at various universities

has not resulted in any students actually attending the program (and only generated two applications). This suggests that for beginning REU sites efforts should be focused on contacting faculty at other institutions that are involved with undergraduate research and teaching to encourage applications. In addition to contacting faculty directly, contacts to departmental advisors (student advisors at some universities) has been a productive tool for generating successful applicants. The key in most cases is making clear that the program is actively recruiting students from a variety of levels (freshmen to seniors) so that faculty and staff can make this information available to a wide group of students. In addition, we clearly specify that the target group of students is from a variety of disciplines, so contacting faculty in multiple disciplines at one school has been a good method of increasing academic diversity in the application pool.

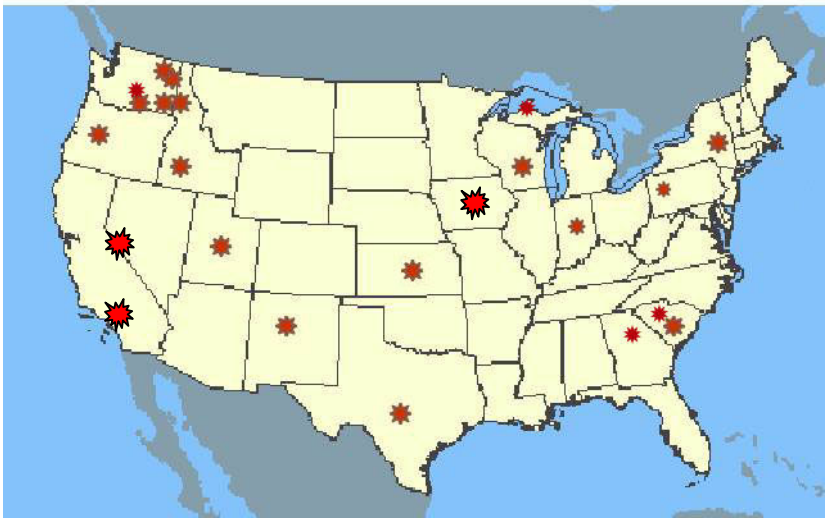

Figure 1. Location of REU participants (by home institution).

Our funding from NSF is enough to support 10 students each summer. Since 2001 we have obtained matching funds from the College of Sciences and the College of Engineering and Architecture that has allowed us to bring an additional two students into the program.

Student Projects

During 2003 students worked on projects ranging from tin whisker formation in microelectronics (a failure mechanism that plagues spacecraft and satellites) to fundamental studies of mechanical deformation using nanoindentation to characterization of the grain structure of titanium alloys after superplastic deformation. All students get the opportunity to use techniques that undergraduates rarely get direct hands-on experience with, such as electron microscopy, atomic force microscopy, and Raman spectroscopy.

We have found that the most effective way of involving undergraduates in a meaningful way in research is through their participation in active projects. These projects are those currently being funded by NSF or other agencies. The REU participants then get the opportunity to interact with faculty, postdocs, graduate students and other undergraduates (which may include other program

participants). Within a larger project, a subset of the project is defined which is possible to complete in one summer's work. It is this coupling of having a large support group of capable, productive students with the individual project that has led to the largest success rate. We have tried to develop specific projects for teams of REU students (where only REU students interact with other REU students) but these have been significantly less productive.

Tables I through V list the student participants and their projects.

Table I. REU Participants and Projects Summer 1999

Student	Major	Project	Home University	State
Molly Kennedy	MSE	TEM and SEM study of tungsten oxidation	WSU	WA
David Eakin	MSE	In situ crystallization of PZT	WSU	WA
Lance Curtis	Met. E.	Rapid prototyping of ceramics	U. Idaho	ID
Ben Gallaher	Chem.	STM and AFM of thin films	WSU	WA
Matt Kontz	ME	Scanning tunneling microscopy	Walla Walla College	WA
Maya Leonetti	Chem.	Organic thin films	WSU	WA
Todd Myers	MSE	Multilayer PZT thin film deposition	WSU	WA
Adam Olson	ME	Indentation for case depth	Boise State U.	ID
Meredith Pritchard	Chem. E	Langmuir Blodgett films of copper phtalocyanine	WSU	WA
Christy Woodcock	ME	Plastic deformation around nanoindentations	WSU	WA

Table II. REU Participants Summer 2000

Student	Major	Project	Home university	State
Susan Beggin	Chem. E	Scanning tunneling microscopy	WSU	WA
Jennifer Benson	ME	Fracture toughness of metal ceramic composites	WSU	WA
Daniel Eakins	MSE	TEM study of titanium oxide films	WSU	WA
Adam Olson	ME	Film adhesion of hard film/soft substrates	Boise State U.	ID
Meredith Pritchard	Chem. E	SPM of organic monolayers	WSU	WA
Nicole Lay	MSE	Functionally graded metal ceramic composites	Rennselear Polytechnic U.	NY
Kevin Morasch	MSE	Hydrogen embrittlement of □ titanium	U. Wisconsin – Madison	WI
Ronald Sanchez Jr.	Chem	Tungsten tip fabrication for STM	Whitworth College	WA
Kirsten Shafer	ME	Stresses in sputtered films	Gonzaga U.	WA
Joy Ann Whigham	Biology	Synthesis and characterization of T-P compounds	Whitworth College	WA

Success Metrics

We measure the success of our REU program by the following metrics:

- Number of participants that go on to attend graduate school in science or engineering
- Participation in the program of women and minorities underrepresented in science and engineering
- Projects that result in work suitable for publication in the archival literature

To date:

- 25 of the 55 participants are women. This accounts for about 45%, which is remarkable considering that women account for only about 20% of engineering undergraduates in the country.
- 22 of 24 of the graduating REU students (92%) have now completed graduate school, are currently attending or applying to graduate school in science or engineering. The REU appears to be a most effective tool for recruiting graduate students
- 23 papers and presentations made possible by REU student's work.

Table III. REU Participants Summer 2001

Student	Major	Project	Home university	State
Katie Blomster	EE	Charge transfer on surfaces	WSU	WA
Elizabeth Cavalieri	EE	SEM of nanowires	U. Idaho	ID
Michael Derkey	ME	Sputtering bi layer films	WSU	WA
William Donigan	ME	Rapid prototyping of ceramics	Utah State U	UT
Martin Held	EE/Phys	Fractography of single crystal YAG	Oregon State U	OR
Maurice Patrick	Chem	Vibrational characterization of electroactive organometallic systems	WSU	WA
Lee Randall	MSE	AFM of PZT/Pt film for a MEMS microengine	WSU	WA
James Martinez	Chem. E	Synthesis of electroactive monomer and polymer systems	WSU	WA
Tammy Oshiro	Chem E	AFM of Langmuir Blodgett films.	WSU	WA
Kimberly Weaver	ME	Nanoindentation of hard films	U. New Mexico	NM
Pablo Diaz	Phys.	OIM and superplasticity of Ti alloys	U. Texas/ Itesm. Campus Monterrey	Texas/ Mexico
Sheldon Bernard	Phys	Ferroelectric thin films	Bennedict College	SC

Table IV. REU Participants and Projects Summer 2002

Student	Major	Project	Home university	State
Pascale Leroueil	Chem	Organic thin films	Whitman College	WA
Michael Turner	Math	Metal infiltrated ceramic composites	Clark Atlanta U	GA
Aaron LaLonde	MSE	Friction stir welding of an Al Alloy	Michigan Technological U	MI
Colin Harris	Phys	Organic thin films	Clemson U	SC
Scott Lovald	ME	Friction stir welding of an Al Alloy	U of New Mexico	NM
Brian Matson	Phys and Eng.	Friction stir welding of an Al Alloy	Fort Hays State U	KS
Arne Backstrom	Chem	Structure and properties of LB films	Whitman College	WA
Susan Pevovar	Phys	Structure and properties of LB films	Carnegie Mellon U	PA
Hemant Doodnauth	Phys	Organic thin films	Benedict College	SC
Kayla Calvert	MSE	Metal infiltrated ceramic composites	Purdue U	IN
Ben McDonald	Phys	Metal infiltrated ceramic composites	Whitworth College	WA
Sheldon Bernard	Phys	Piezoelectric thin films	Benedict College	SC

Table V. REU Participants and Projects Summer 2003

Student	Major	Project	Home university	State
Cole Petersburg	MSE	Influence of metal ion doping on calcium phosphate ceramics	Iowa State U	IA
Elizabeth Withey	MSE	Influence of metal ion doping on calcium phosphate ceramics	Purdue U	IN
Jason Swaim	Physics	Superplastic deformation of titanium	Pomona College	CA
Dana Hansen	ME	Development of new wood based composites by thermal analysis	U. Nevada Reno	NV
Mallory Mentele	Chemistry	Synthesis and structural characterization (spectroscopic and microscopic) of novel electroactive compounds.	Gonzaga U	WA
Krista Nishida	Chemistry	Nanomechanical studies of highly organized semiconducting molecular thin films.	Whitman College	WA
Mark Anderson	MSE	Defects in single crystals for optical applications	Michigan Tech U	MI
Jon Winterstein	MSE	Characterization of tin whiskers	WSU	WA
Monica Zosel	ME	Raman spectroscopy of PZT films for stress analysis	WSU	WA
Elizabeth Hertzog	MSE	Nanoindentation of Rat Vibrissa	Purdue University	IN
Coralee McNee	MSE	Dislocation nucleation during nanoindentation: Length scale effects	Cal Poly U	CA
Dane Stevenson	Biochem	STM analysis of organic films	Whitman College	WA

Student Comments

At the end of each summer we distribute an evaluation form that the REU participants complete. The comments we have received have been overwhelmingly positive. The principal benefits that participants see with the program are that it gives them a taster of what graduate school is like, they get to use advanced characterization tools, they get to work closely with faculty members on active research programs, and they get to meet students from other schools. The following are very typical comments that we have received over the past five years.

> "I feel that I have learned an incredible amount of knowledge that I can use for future classes and jobs." REU participant summer 1999

> "We get to see how research is conducted first hand." REU participant summer 2000

> "The amount of cross disciplinary work that goes on is amazing, and I think anyone with an interest in science would have a good time." REU participant summer 2001

> "This program has truly enlightened me concerning research." REU participant summer 2003

> "Because of the program, graduate school is definitely more enticing." REU participant summer 2003

"I am definitely looking into attending graduate school. After working on my project and working with the people in my department, I knew this was what I wanted to do ..." REU participant summer 2003

Acknowledgment
The financial support of the National Science Foundation Division of Materials Research REU program under contract number 0139125 is greatly appreciated.

References

1. National Science Foundation, REU web page www.nsf.gov/home/crssprgm/reu
2. Washington State University REU web page www.mme.wsu.edu/~reu
3. *Effect of Thermal Treatment on Failure Modes in Tungsten Wire*, P.P. Bourque, D.F. Bahr, and M.G. Norton, Materials Science and Engineering A, 298, 73-78 (2001)
4. *Evolution of Plastic Zone During Nanoindentation,* C.L. Woodcock and D.F. Bahr, Scripta Mater., 43, 783-788 (2000)
5. *Phase Transformations in Sol-Gel PZT Thin Films,* D.P. Eakin, M.G. Norton, and D. F. Bahr, in: *Materials for Novel Oxide Based Electronics*, Proceedings of the Materials Research Society, 623, 185-190 (2000)
6. *Structural and Mechanical Characteristics of Anodic Oxide Films on Titanium*, M. Pang, D.E. Eakins, M.G. Norton, and D.F. Bahr, Corrosion, 57, 523-531 (2001)
7. *Relationships Between Film Chemistry, Structure, and Mechanical Properties in Titanium Oxides,* M. Pang, D.E. Eakins, M.G. Norton, and D.F. Bahr, in: *Structure-Property Relationships of Oxide Surfaces and Interfaces*, Proceedings of the Materials Research Society, 654, AA3.41.1-.6 (2001)
8. *Plastic Zone Development Around Nanoindentations*, C.L. Woodcock, D.F. Bahr, and N.R. Moody, in: *Fundamentals of Nanoindentation and Nanotribology II*, Proceedings of the Materials Research Society, Q7.14.1-Q7.14.6 (2001)
9. *The Effects Of Hydrogen On Deformation And Cross Slip In A BCC Titanium Alloy*, K.R. Morasch and D.F. Bahr, Scripta Mater., 45, 839-845 (2001)
10. *Processing and Reliability Issues in PLZT and PZNT Thin Films via Sol-Gel,* P. Banerjee, D. Bahr and A. Bandyopadhyay, Symposium on Sol-Gel Thin Films, Pacific Coast Regional Meeting of the American Ceramic Society, October 27-29, (1999)
11. *Indentation Techniques to Measure the Adhesion of Hard Films on Soft Substrates*, D.F. Bahr and A.L. Olson, TMS 2001 Annual Meeting, General Abstracts Adhesion Symposium February (2001)
12. *Slip Band and Step Formation Around Small Scale Indentations*, D.F. Bahr, C.L. Woodcock, and K.R. Morasch, in: *Material Instabilities and Patterning in Metals,* Proceedings of the Materials Research Society (2001)
13. *Micro-Machining Of PZT-Based MEMS*, T. B. Myers, S. Bose, J. D. Fraser and A. Bandyopadhyay, in: Proceedings of the Innovative Processing and Synthesis of Ceramics, Glasses and Composites, American Ceramic Society (2001)
14. *Polymer-Ceramic Composites for bone Graft Applications,* S. Bose, T. Myers, A. Bandyopadhyay and H. L. Hosick, Polymer Preprints, 41, 1620 (2000)
15. *Electro-Mechanical Coupling And Power Generation In A PZT Micro-Engine,* D.F. Bahr, K.R. Bruce, B.W. Olson, L.M. Eakins, C.D. Richards, and R.F. Richards, in: *Materials Science of Microelectromechanical Systems (MEMS) Devices IV*, Proceedings of the Materials Research Society. 687, pp. 4.3.1-6 (2002)
16. *Thin Film Fracture During Nanoindentation Of Hard Film – Soft Substrate Systems,* M. Pang, K.D.Weaver, and D.F. Bahr, in: *Thin Films Stresses and Mechanical Properties IX,* Proceedings of the Materials Research, 695, pp. L7.2.1-6 (2002)
17. *Nanoindentation and Orientation Imaging: Probing Small Volumes and Thin Films for Mechanical Properties*, D.F. Bahr, K.A. Nibur and K.R. Morasch, Journal of Electronic Materials, 31, pp. 66 - 70 (2002)

18. *Superior superplastic behavior in fine-grained T-6Al-4V sheet*, S. N. Patankar, J. P. Escobedo, D. P. Field, G. Salishchev, R. M. Galeyev, O. R. Valiakhmetov and F. H. (Sam) Froes, Journal of Alloys and Compounds, 345, pp. 221-227 (2002)
19. *Nanoparticle Formation in Microchannel Glass by Plasma Enhanced Chemical Vapor Deposition,* D.N. McIlroy, J. Huso, Y. Kranov, J. Marchiek, C. Ebert, S, Moore, E. Marji, R. Gandy, Y.-K. Hong, M.G. Norton, E. Cavalieri, R. Benz, B. Justus, and A. Rosenberg, Journal of Applied Physics, 93, 5643 (2003)
20. *Indentation Induced Film Fracture in Hard Film – Soft Substrate Systems,* D.F. Bahr, C.L. Woodcock, M. Pang, K.D. Weaver, and N.R. Moody, International Journal of Fracture, 119, pp. 339-349 (2003)
21. *A Study of Fracture and Defects in Single Crystal YAG,* D.E. Eakins, M. Held, M.G. Norton, and D.F. Bahr, Journal of Crystal Growth (submitted for publication 2003)
22. *Molecular Orientation of F16CoPc on Various Substrates*, P. Leroueil, C. Harris, H. Doodnauth, K.W. Hipps, and M.G. Norton, Abstracts of Papers, 225th ACS National Meeting, New Orleans, LA, March 23-27, (2003)
23. *Hydrogen and Deformation: Nano- and Microindentation Studies*, D.F. Bahr, K.A. Nibur, K.R. Morasch, and D.P. Field, JOM, 55, pp. 27-50 (2003)
24. *Characteristics of Tin Whiskers Formed on Sputtered-Deposition Films—An Aging Study*, J. Winterstein, J.B. LeBret, and M.G. Norton, Journal of Materials Research (in press 2004)
25. *Spatially Dependent Mechanical Properties of Rat Whiskers*, E.K. Herzog, D.F. Bahr, C.D. Richards, R.F. Richards, D.M. Rector, Neuroscience Letters (in press 2004)

Biographical Information

M. GRANT NORTON is Professor in the School of Mechanical & Materials Engineering and Chair of the Materials Science Program. He has won several awards for teaching including the ASEE Outstanding Teaching Award for the Pacific Northwest. Dr. Norton has over 125 publications in the archival literature and is co-author of *X-Ray Diffraction: A Practical Approach* published by Plenum.

DAVID F. BAHR is Associate Professor in the School of Mechanical & Materials Engineering. He received the 2003 Bradley Stoughton Award for Young Teachers from ASM and was a recipient of a PECASE/DOE Presidential Faculty award. Dr. Bahr has over 70 publications in the archival literature.