Enriching the Research Experience for Undergraduates (REUs) in Biomedical Engineering

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Abstract

Researchers in VaNTH--a National Science Foundation (NSF) consortium of schools with strong bioengineering departments, namely Vanderbilt, Northwestern, the University of Texas at Austin, and the Harvard-MIT Division of Health Sciences and Technology-- have developed an enriched program for the undergraduates from other institutions who participate in their efforts through the NSF-funded Research Experience for Undergraduates (REUs). Although the VaNTH REU program is designed primarily to involve these undergraduates in the VaNTH mission—the development of cutting edge curricular material for bioengineers that is based on research in the learning sciences about how bioengineers learn-- the enriched program also helps students develop the core competencies necessary for professional success, such as problem analysis, team management, written and oral communication, and professional ethics. Students are mentored by professionals in ethics and communication, participate in special study groups, and complete a report and presentation based on their research. Preliminary evaluation of this enriched summer experience points to its success and suggests that the REU program is a good setting for preparing undergraduates to be more capable members of their profession.

Introduction

Since bioengineering programs throughout the nation have outpaced the development of appropriate teaching materials, a consortium of schools with strong bioengineering departments —**V**anderbilt, **N**orthwestern, the University of **T**exas at Austin, and the **H**arvard-MIT Division of Health Sciences and Technology (VaNTH)—is developing new educational technologies for the field. VaNTH operates as a National Science Foundation (NSF) Engineering Research Center (ERC). The mission of the VaNTH ERC is to develop cutting edge curricular material, based on research from the learning sciences about how bioengineers learn and how knowledge in bioengineering is structured. The long term goal is for these materials to be expanded and used by institutions throughout the country, not only in bioengineering but also in the life sciences and in industry.[1,2, 3, 4]

As a part of this effort, VaNTH researchers have developed an enriched program for undergraduates from institutions outside the VaNTH consortium through the NSF-funded Research Experience for Undergraduates (REUs). The VaNTH REU program is designed primarily to involve these undergraduates in the excitement of VaNTH research. However, the program also reflects the recent emphasis in engineering education on the development of undergraduates' core competencies, i.e., those skills necessary for professional success regardless of field, e.g., problem analysis, team management, written and oral communication,

etc.[5] In addition to being mentored by a professor from engineering, bioethics, or the learning sciences, all VaNTH REUs are coached by faculty from ethics and communication and some have participated in a pilot critical reading group that discusses the educational theories underlying the Center's work.

Early indications suggest that this enriched, or integrated, REU experience is valued by students, faculty, and VaNTH administrators. This paper describes the structure of the VaNTH REU program and the kinds of assignments and teaching strategies that help students understand learning theory and develop core competencies in professional ethics and communication. In particular, the enriched REU program helps students (1) identify and examine ethical issues related to their work, (2) develop their ability to discuss those issues effectively with peers and interested members of the public, and (3) understand the four dimensions of *how people learn* as they relate to REU projects and more broadly to successful learning environments. Finally, we urge other REU programs to consider an enriched or integrated approach, arguing that REU programs offer tremendous opportunities for helping future engineers become better teachers, better communicators, and more responsible members of their profession.

The VaNTH REU Program

VaNTH has been offering an REU program since 2000, with a total of 30 students attending from 23 institutions:

Carnegie Mellon - n=1	Case Western University - n=1
Duke University - n=1	Hope College - n=1
Lawrence University - n=1	Manatee Community College - n=1
Marquette University - n=2	Mercer College- n=1
Middle Tennessee State - n=1	Milwaukee School of Engineering - n=1
Mississippi State University - n=1	North Carolina State - n=1
Northwestern University - n=1	Oregon State - n=1
Rhode Island School of Design - n=1	Rice University - n=4
-Texas A&M - n=2	University of Pennsylvania - n=2
University of Rochester - n=2	University of Southern California - n=1
University of Kentucky - n=1	University of Miami - n=1
Vanderbilt University - n=1	

Most of the REUs work on one of the 15 domain projects initially identified by VaNTH as significant areas in bioengineering, such as those listed in Table 1. Thus, REUs are involved in projects at all participating VaNTH institutions.

Table 1. Bioengineering Education Domain Areas, Leaders and Institutions

Systems Physiology	John Troy	Northwestern University
Tissue Engineering	Shu Liu	Northwestern University
Biotechnology	Todd Giorgio	Vanderbilt University
Biotransport Phenomena	Bob Roselli	Vanderbilt University

Bioenergetics & Thermodynamics	Art Overholser	Vanderbilt University
Biomedical Optics	Jay Walsh	Northwestern University
Biomedical Instrumentation	Bob Galloway	Vanderbilt University
Biosignal Analysis	Rich Shiavi	Vanderbilt University
Biomedical Imaging	Cynthia Paschal	Vanderbilt University
Design	Paul King	Vanderbilt University
Biomaterials	Fred Schoen	HST
Biomechanics/Rehab Engin	Marcus Pandy	University of Texas, Austin
Bioengineering Ethics	Stephanie Bird	HST
Biology	Rob Linsenmeier	Northwestern University

Interdisciplinary teams do research in each domain and therefore the REU program in VaNTH is a rich and complex experience for participants. Each domain team consists of a domain leader, peers within VaNTH who are experts in the field, and one or more industrial representatives within the field. Projects within the domain also include an educational assessment expert, a learning scientist, and graduate and undergraduate students from the VaNTH member schools. During the summer, REUs from this and other REU programs (generally no more than 1-2 REU students working in any one domain area) join a domain project and contribute a defined component. Consequently, VaNTH REUs witness the interaction between domain experts (faculty and industry) and learning scientists, work with other undergraduates working on the project from the host institution, and, on an individual basis, may be mentored by graduate students, faculty and/or industrial representatives.

Each domain area is responsible for first developing a taxonomy or knowledge base for that domain. Once a domain's taxonomy is developed in sufficient detail, domain leaders decide which education modules, and related granules (video clips, simulations, class notes, knowledge-based questions, etc.), should be developed. REUs have worked on developing relational databases that are used to store and display the taxonomic structure of the domains and others have worked on developing educational materials ("modules" and "granules"). REU projects include developing video or audio tracks of faculty lectures or programming or drafting plans for implementing interactive simulations. REUs might also participate in VaNTH assessment and evaluation activities, developing web-based forms for surveys, spreadsheets, or assisting with the compilation and statistical analysis of assessment data. Some REUs, especially those with a background in education, have joined the Learning Science teams and helped to evaluate the impact of new educational technologies and materials. Others have had the opportunity to work with local middle and high school programs to improve the teaching of core science and math education. Finally, REUs can be involved in projects in information technology and continuous education, with asynchronous learning networks. REUs at each VaNTH site are supervised by the VaNTH administrator at that site, who helps them develop socially as well as intellectually. They take field trips as a group, meet for social events, and learn about each other's home institutions as well as their VaNTH host institution.

From its inception, the VaNTH ERC recognized the importance of including core competencies, such as design, professional ethics, and communication, into its bioengineering taxonomy. Ethics and Design are in fact VaNTH domains, and REU students have participated in those, and have been given instruction in technical communication, from the Center's inception. However, as VaNTH modules were developed, and faculty increasingly recognized the pedagogical effectiveness of the learning theories underlying the new curricular materials, VaNTH faculty began to emphasize that all instruction, including that of the REU program, reflect the problem-based approach that is central to VaNTH. This approach is based largely on key principles identified over the past 30 years of research on teaching and learning and explained in *How People Learn: Brain, Mind, Experience and School* (HPL)[2]. VaNTH modules use an HPL approach to teach bioengineering concepts in challenge- or problem-based settings and in classroom environments that are (1) learner-centered, (2) knowledge-centered, (3) assessment-centered, and (4) community-centered. Since these modules are proving to increase student learning, it follows that core competencies in bioengineering should be taught in a similar way, i.e., undergraduates in bioengineering should learn about professional ethics, design, and communication in an HPL setting that presents real problems that they find meaningful.

Thus the VaNTH REU program now weaves core competency instruction from two areas into the students' research projects, and, at one site, has piloted a symposium on HPL that advances student understanding of learning and learning science.

Integrating Core Competency Instruction into the REUs' Research Experience

In the integrated professional ethics and technical communication (TC) segment, the instructors set joint goals for their REU summer courses, develop assignments in common, and give students coordinated feedback. The mentor for all ethics projects is Stephanie J. Bird, the domain leader in ethics for VaNTH and primary author of the bioengineering ethics taxonomy. Penny L. Hirsch, the technical communications instructor, is an expert on team teaching, learning communities, and problem-based learning who co-chairs Northwestern's project-based freshman design course, "Engineering Design and Communication."

To meet the learning goals of the integrated ethics/TC program students strive to:

- Expand their understanding of ethical issues associated with biomedical engineering
- Explore the complexity of at least one of these ethical issues
- Understand the broad ranging, multifaceted nature of engineering communication and the concept of "core competencies" in biomedical engineering
- Improve in at least three communication skills areas that they identify as important to their work; examples are interviewing experts, integrating texts and graphics, writing clear technical descriptions, constructing parallel lists, writing clear, readable PowerPoint slides, writing procedures
- Improve their ability to use new communication technologies, such as PowerPoint, Prometheus (an online learning environment similar to BlackBoard), and teleconferencing
- Improve their ability to communicate effectively in groups, especially in giving and using feedback
- Develop an increased awareness of key communication concepts, such as audience analysis, the relationship of purpose to genre, and the importance of feedback and revision

- Recognize similarities between problem-solving in design and problem-solving in communication
- Develop a greater comfort level with a variety of communication media

Each student identifies and then examines in depth an ethical issue related to his or her individual research, writes a paper on that topic, and presents a teleconferenced PowerPoint presentation to other students, VaNTH faculty and administrators, and teachers from the public schools. In the summer of 2002, after receiving guidance from their domain mentors, REU students examined a variety of issues including the following:

- Bias in educational studies: Can we trust our data?
- Economic disparities among schools and resource allocation: Is it right to develop exciting new science curricula for schools who will not be able to afford the expensive equipment that the new curricula might require? What happens to curricular innovations when grant money expires?
- College students as human subjects: Are college students exploited in the name of scientific research? Are VaNTH's own consent procedures adequate to protect the students who participate in VaNTH's educational initiatives?
- The marketing of LASIK surgery: do patients fully understand the risks of LASIK surgery? Do advertisements mislead consumers by minimizing the risks?
- Issues of cost, efficacy, and safety faced by pharmaceutical companies: If a company simply follows FDA requirements for purity, is that good enough?

Thus, throughout the summer, as students pursue their research, they also explore ethical issues associated with their project and enlarge their understanding of the ethical implications of bioengineering. Once students choose a topic, they post ideas to other REUs in their online study groups and submit partial and full drafts to their instructors for comments.

The syllabi for the professional ethics and technical communications components are interwoven so that all of the REUs' written assignments stem from their research or ethics projects. (see Figure 1):

2002 Dates	*Session*	*Ethics Topic*	*TC Topic*
June 13	1	Intro to Prof. Ethics 2002	Intro to TC 2002
June 17	2	Meet with faculty; identify ethical issues	TC Planning
June 24	3	Phone conferences with PLH—discuss paper ideas	Phone conference: TC planning
July 1	4	Finalize topic choice	Reading and writing for July
July 8	5	Mini teleconferences:	Mini teleconferences: ethics

		ethics paper	paper
July 15	6		Research, drafting, responding
July 22	7	Draft due: ethics paper	Draft of ethics paper due
July 29	8	Draft slides due for oral presentation	Draft slides due for practice presentation
Aug 2	9	Ethics paper due—revised based on feedback on draft	Ethics paper due before Aug 5
Aug 5	10	Practice presentations	Practice presentations
Aug 8	11	Final presentations	Final presentations
Aug 9	12	Summer wrap-up	Wrap-up

Figure 1: Coordinated Syllabi for Professional Ethics and Technical Communication

Assignments are coordinated. For example, session 5 in the Ethics component covers both ethics and communication, and students find the same description in the assignments for TC:

> Topic for Session 5
> Mini teleconferences on ethics topics
>
> Class Plan:
> Monday and Tuesday, July 8-9: Mini teleconferences with PLH and 2-3 REUs from different sites. You will present 2-3 ppt slides describing your issue for the ethics paper (what is it and why). The goals of these teleconferences are fourfold: in an informal setting, to (1) practice using the technologies you will use for final presentations in August, (2) present your ethics topic and explain why its important, (3) develop ideas through conversation and (4) practice asking useful questions and providing feedback. The technologies we are focusing on are PowerPoint and teleconferencing with slide backup.

Since the REUs know that they will have to present their projects at the end of the summer, they are willing to work in small groups, both online and in person, to improve their ability to communicate clearly and effectively in a variety of new genres. When they submit ideas and drafts, they receive feedback on both ethics and communication from both instructors. They begin to see that communication is much more complicated than editing, that ethics and communication are inter-related, and that both are integrally linked to their primary research.

A Critical Reading Seminar of How People Learn

The four dimensions (knowledge, learner, assessment, and community) of a successful learning environment identified and articulated in *How People Learn* (HPL) inform the instructional design and development of the educational materials produced by the VaNTH ERC. Since its inception, REU students have had exposure to the HPL principles through a plenary session on the work of the VaNTH ERC, by working on their VaNTH REU project, and in interactions with VaNTH researchers. However, in conversations with REU students during the first two years of the program, it became clear that most REU participants were gaining little understanding of the HPL framework. Students reported that they either didn't "…see how HPL fit" into the work that they were doing, or they incorrectly identified an instructional design template, that is commonly utilized in VaNTH materials, as the whole of HPL. In an effort to provide more formal instruction of the HPL framework and to make obvious the implications of the learning sciences (HPL) for work in VaNTH, a critical reading seminar was organized by Mark D'Avila, VaNTH administrator and learning science coordinator for the HST portion of the consortium, and piloted in 2002 at HST. In addition to the REU students (n=3), other undergraduate and graduate students working on VaNTH projects (n=13), and Stephanie Bird as well as the seminar director, Mark D'Avila participated.

The learning objectives of the critical reading seminar included the following:

- To have fun and get to know one another better
- To have a basic understanding of the four dimensions of a successful learning environment as articulated in *How People Learn*
- To begin understanding the theoretical underpinnings of the learning sciences work being done in the VaNTH ERC (with focus on specific REU projects
- To practice leading a group discussion

The seminar met weekly, was organized into seven sessions (see Figure 2), and was discussion based. Two seminar participants were identified as the leaders for each session, and the seminar director was the discussion leader during the first and final sessions. Discussion leader pairs were assigned the task of drafting an outline of what they thought were the critically important areas to discuss relative to the assigned reading. Once written, leader-pairs met with the seminar director to review and (often) revise their talking points. All reading assignments were taken from *How People Learn* and were provided in a packet during the REU Orientation.

Week 1	Introduction Pgs. 6-21
Week 2	Learning and Transfer Pgs. 53-66, 73-78
Week 3	Design of Learning Environments Pgs. 131-149
Week 4	Experts and Novices Pgs. 31-50
Week 5	Technology and Learning Pgs. 213-224, 226-230
Week 6	Examples of Effective Teaching Pgs. 155-157, 164-180
Week 7	HPL as is relates to VaNTH

Figure 2: Syllabus for the *How People Learn* seminar

Seminar participants reported that they enjoyed the discussion group, both from the perspective of a learning experience and also as a means of socializing with other VaNTH participants. A sampling of the qualitative responses received on surveys completed during the last seminar meeting include: 1) "…HPL is common sense, but not until you read and think about it"; 2) "I don't think I would have understood how the different pieces of VaNTH fit together had we not had an opportunity to meet as a group so often…"; 3) "I have been doing VaNTH work for over a year but this is the first time that I understand how HPL is different from a legacy cycle (instructional design template)."; 4) "VaNTH is much more complex than I had initially thought."; and 5) "Now I know why some classes I've had were so bad! …all teachers should have to take a class in how people learn…".

In addition to a syllabus, talking points for each session were documented in a standardized format. VaNTH is now considering the feasibility and logistics of holding the *How People Learn* seminar at the other VaNTH sites.

Assessment and Evaluation

Preliminary evaluations of enhancements to the VaNTH REU program have been positive. Site administrators and the director of the REU program all say that the student presentations have improved markedly and that the REUs demonstrated a much more thorough understanding of ethics in bioengineering. Plans to offer the enhancements again next year are underway.

Instructors noted improvement in both professional ethics and communication. In ethics, the most heartening result is that students began to recognize both the variety and complexity of ethical aspects of the work they were doing. In communication, students demonstrated the greatest gains in their management of PowerPoint slides. They learned not only how to make their slides more professional looking and easier to read, but also how to link slides to make a coherent argument. Students learned that communication in bioengineering is multi-faceted, involving writing, speaking, and communicating graphically. Several REUs expanded their understanding of research, doing more with interviews than they had done in the past.

Students' opinions were gathered through pre- and post-course memos written about technical communication and through a post-summer questionnaire sent to all 11 REUs. On a 4-point scale, with 4 meaning "a great deal" and 1 meaning "not at all," eight students said that the TC component of the REU program has influenced their current written and oral reports "somewhat" or "a great deal." The average answer to that question was 3, with a few students saying that they haven't been asked to write anything since their REU experience. Students who offered comments said they gained the most from improving their presentation and PowerPoint skills. Also mentioned were improvements in writing memos and emails, giving and getting feedback on writing, communicating online via Prometheus, and being more willing to seek help on writing in the future. One student said, "I liked having to write rough drafts, receiving feedback, and producing a more polished version." Another said that the technical communications helped her "focus on what the audience wanted to hear and present material in an organized way."

These comments in the questionnaires confirmed points that students made in their post-course memos to the TC instructor.

Using the same scale, nine REUs said that the ethics component of the program increased their awareness of ethical issues in their classes "somewhat" or "a great deal." The average answer to this question was 3.3. Students who offered comments said that the ethics component gave them a good overview of key issues in this area, was their first exposure to ethical issues in bioengineering, would change the way they look at specific aspects of bioengineering in the future, and has helped to prepare them for problems they may encounter in their professional lives. One student said that the ethics component "influence[d] the way I view the material I study. . . . [It] heightened my awareness of the ethical implications . . . woven throughout my field." Another said that the ethical component "made me think about what I was working on in an entirely different light." A third said that the ethics project "make[s] you think not only as an engineer but makes you look at the profession from a wider view and . . . see how your work could affect other people."

Students were also asked to rate the degree to which it was useful for them to learn about the "How People Learn" model, which is unique to the VaNTH summer program compared to summer programs in traditional labs. Eight students said that it was "very" or "somewhat" useful, with the average answer being 2.9. One said that the "weekly HPL discussion group at MIT . . . [was] particularly useful and interesting. [It] was a lively interesting forum for a variety of ideas . . . [and] where I learned the most about the theoretical underpinnings for the educational work we are doing."

Very few students recommended changes to the REU program, and most said that they would recommend it to their peers.

Finally, as part of our initial evaluation, students developed concept maps for ethics and technical communication. These are in the process of being blind reviewed now. The student concept maps from the end of the summer are being compared to their maps from the beginning of the summer, and both sets are being compared to concept maps developed by experts. The concept maps will help identify more specifically what students learned.

Discussion: Implications for the Structure of Future REU Programs

While the enhancements in the VaNTH REU program did not appeal to every student, the overall response was positive. Student enthusiasm in the final presentations makes an especially strong argument for more collaborative teaching for REUs and biomedical and bioengineering undergraduates in general. We believe that such instruction, particularly in core competencies like ethics and communication, will help biomedical undergraduates better appreciate the complexities of their field and explore the broader social and political implications of the research. That, and a more thorough understanding of learning theory, will make tomorrow's bioengineers better practitioners and more capable teachers.

Acknowledgements

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[5] Both industry representatives and ABET evaluators emphasize the importance of core competencies in engineering. See, for example, "Educating Tomorrow's Engineers," *ASEE Prism,* May/June 1995, pp. 11-15.

Biographies

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MARK D'AVILA – is assistant director of the VaNTH ERC and learning sciences coordinator for the HST portion of the consortium.