

## **AC 2008-884: A UNIQUE RESEARCH EXPERIENCE IN BIOENGINEERING EDUCATION FOR UNDERGRADUATES IN THE VAN TH REU**

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# **A Unique Research Experience in Bioengineering Education for Undergraduates in the VaNTH REU**

## **Abstract**

Most Research Experience for Undergraduates (REU) programs are designed to provide summer research opportunities in a particular domain of engineering or science. The VaNTH REU has been unique in focusing instead on education research projects in bioengineering. These projects allow students from various fields to gain a different perspective on their education while making the decisions about content and pedagogy that instructors usually make. After an introductory session at Vanderbilt, students spend the next nine weeks working with mentors from Vanderbilt University, Northwestern University, Massachusetts Institute of Technology or the University of Texas at Austin. While at these sites, students meet weekly by video- or tele-conference to report on their projects. Work on ethics and communication were integrated into the REU experience. The REU students, who are mostly in engineering, have become engaged in the process and methods of engineering education research and, in many cases, have made substantial contributions to the development and/or classroom evaluation of educational materials. At the same time, they have learned a particular field of bioengineering more deeply. This paper discusses the VaNTH REU program and illustrates the contributions of REU students to successful innovations in bioengineering pedagogy. While it would be difficult to replicate the VaNTH REU program in its entirety, many of its components are transferable and could help students who are considering faculty careers or graduate school in engineering education.

## **1. Introduction**

### **1.1 The VaNTH ERC**

The VaNTH Engineering Research Center (ERC) in Bioengineering Educational Technologies was founded in 1999 to do research in learning science, learning technologies, and bioengineering curriculum. A partnership of Vanderbilt University, Northwestern University, the University of Texas at Austin, and the Division of Health Sciences and Technology at Harvard and the Massachusetts Institute of Technology, VaNTH has investigated many areas of engineering education, with a focus on bioengineering. VaNTH has studied the effectiveness of challenge-based instruction, has contributed to the dialog on the development of students' adaptive expertise, has studied the development of pedagogical knowledge and novel teaching methods by faculty, has developed and evaluated new learning technologies, and has developed approaches to help bioengineering students communicate more effectively and understand ethical issues related to their field. In the course of this work, VaNTH has produced educational materials for others to use that have the potential to impact all bioengineering and biomedical engineering programs in the country. In addition, since bioengineering integrates engineering and the life sciences, subsets of materials developed in the ERC will also impact education in these fields. Further, some of the materials have been disseminated for middle school and high school students. This paper discusses how a Research Experience for Undergraduates (REU) program engaged undergraduates in this work, benefiting both the students and the VaNTH ERC and argues that similar programs, or even aspects of this program, would be very helpful to students considering faculty careers in engineering or graduate school in engineering education.

## **1.2 Rationale for an REU program in bioengineering education research**

Almost any research experience is valuable as a component of an undergraduate education, as it allows the student more independence than in the classroom, shows them how research is done, and helps them develop professional communication skills. The VaNTH REU program shared these basic virtues, but went beyond them in specific ways best appreciated by considering the context of the VaNTH ERC. Most engineering faculty receive little education in learning science or pedagogical principles, and bioengineers are no exception. The VaNTH ERC provided an opportunity for bioengineering faculty, and the REU students, to learn from and work with learning scientists and assessment experts. VaNTH work has been a partnership of engineers and learning scientists. In some contexts, including many areas of K-12 education, learning scientists/education researchers are familiar with content imparted in the classroom, and this facilitates their education research. However, effective engineering education research is different. Few learning scientists have the content knowledge to know where students might be having difficulty, and lack the experience to know what skills and mental habits engineering students need to possess by the time they graduate. In turn, few engineering faculty are good at analyzing their own teaching methods, recognizing how people learn, or designing studies that rely on social science research methods. Through the collaboration of learning scientists and engineers, these disparate skills have been brought together. As discussed extensively in other publications from VaNTH<sup>1-8</sup>, this collaboration has improved teaching methods and design of teaching materials, made bioengineering faculty more reflective about their teaching methods, and fostered a change in the way bioengineering faculty create a classroom experience. In addition, it has brought proven social science research methods to bear on evaluating innovations in engineering education.

Beyond benefiting the individuals at the VaNTH institutions, VaNTH has served as a model for both improving engineering education practice and furthering engineering education research. Continuing to improve engineering education requires more engineers who know something about educational research and learning theory, like those who took part in VaNTH, and some who pursue engineering education research as a field of study. However, there are few opportunities for engineering students to engage in education research. Filling this gap was one rationale for the VaNTH REU. We wanted to encourage students who want to do graduate work in engineering education, which is now possible at a small number of universities, but more importantly to impart knowledge about good pedagogy and engineering education research to a larger group of potential educators.

A second part of the rationale for the REU program was a practical issue of staffing. Engineering education research being no less time-consuming than bioengineering research, few of the VaNTH bioengineering faculty could devote all their research time to education. Further, most of the graduate students in bioengineering programs are there primarily to learn bioengineering, not education. Thus, even though VaNTH had access to some learning science graduate students and postdoctoral fellows, personnel for projects was limited. Undergraduates in the REU program helped fulfill this need and made important contributions to VaNTH's work.

## **2. Description of program**

### **2.1 Orientation**

The REU program started with an orientation at Vanderbilt where students received an introduction to the program, our expectations of them, and what they could expect from the site coordinators, faculty, and other mentors. Students were also introduced to the main learning science concepts that all would employ in some fashion in their research projects. These concepts, based on the National Research Council's report *How People Learn* (HPL) <sup>9</sup>, and on subsequent work in challenge-based instruction <sup>5,6</sup> and the development of adaptive expertise <sup>10-12</sup> differentiated the approach taken in VaNTH from the development of more typical texts or educational materials. Learning Science experts met with the students to provide a basic introduction to HPL and help them to understand the difference its principles can make in the classroom. Students were also introduced to the Legacy Cycle, a basic method of enacting HPL theory frequently used in VaNTH modules. When VaNTH proprietary learning technologies were sufficiently mature, REU orientations included an introduction to them. Whether or not their research would directly involve the software, this visual technology helped students see how learning activities within a module might be sequenced according to HPL. As the software continued to evolve, several REU students were among the first to utilize it to construct new course modules.

Students also worked through introductory sessions with experts in ethics and technical communication and began to develop a team atmosphere since ethics, communication, and team skills are all considered important for future engineers. Team-building was done through social events and getting-acquainted activities, a vital part of the orientation because students would soon be dispersed to different locations and interacting primarily through teleconferencing. During the orientation students also participated in laboratory and industrial field trips so that they were exposed to the variety of career choices available in bioengineering and related fields. At the end of the orientation, students went to their different sites to begin their research projects.

### **2.2 Coordination across sites**

Coordination across sites was vital to the success of the program. Overall coordination was done at Vanderbilt with one administrator who handled the orientation program, publicity of the program, recruitment of students, financial management, and overall record-keeping. Each site also had a coordinator. These individuals helped the students with administrative matters, made sure that videoconferences occurred smoothly, and monitored student progress. We attempted to insure that each site had at least two REU students, and attempted to include students in meetings and seminars with a larger group of education researchers. Each student had a principal mentor, but also interacted with other students. The most important communication was a weekly teleconference, using speakerphone and NetMeeting for sharing slides with students from all sites, as explained below. For final presentations, students used videoconferencing

### **2.3 Research projects**

REU student research projects generally fell into one of three classes. First, they may have helped to develop or refine educational materials, primarily courseware modules, for university courses in bioengineering, using the *How People Learn* <sup>9</sup> principles. This is the

primary method by which students learned about effective pedagogy in bioengineering and how to incorporate new technologies to facilitate teaching and improve learning. For these students, continued training in learning theory beyond orientation was often necessary for the successful completion of their projects. For this, the faculty member may have referred them to the HPL book as a resource, or the faculty may have modeled the concepts of HPL in helping them understand what needed to be done. If students were creating modules, most faculty mentors had them use the Legacy Cycle model, thus incorporating understanding of learning theory into the project. During the hands-on phase of project development, students' misconceptions and lack of understanding could be observed and addressed more fully. In many instances, a VaNTH specialist in learning science was available as a resource for students who needed further guidance. In some cases, the specialist acted as a co-mentor for the project, helping to train both the faculty mentor and the student during the summer. In another type of project, students assisted in planning experiments and/or analyzing data related to assessment of student learning in modules that they or others developed. This also required their understanding of learning science and emphasized the importance of assessment in education research. Finally, some REU students worked on outreach projects involving challenge-based modules for middle- and high-school students developed at Vanderbilt (Vanderbilt Instruction in Biomedical Engineering for Secondary Science – [www.vanth.org/vibes](http://www.vanth.org/vibes)) or Northwestern (Get a Grip - [www.middleschoolengineers.com](http://www.middleschoolengineers.com)). In all cases, the students generated a written report and an oral presentation about their work by the end of the summer. Some have presented their work at a scientific meeting or have been co-authors on the work of a VaNTH investigator. A breakdown of the areas in which students did their projects is shown in Table 1.

**Table 1. Distribution of student projects by domain across 9 years**

ERC Thrust Area or Domain	Number of Students
Learning Tech	4
Learning Science	13
Bio-optics	9
Biomechanics	11
Biotechnology	10
Bioethics	7
Systems Physiology	18
Imaging	2
Design	7
Biotransport	4
Bioinformatics	4

## 2.4 Ethics component

Since ethics is a crucial component of undergraduate engineering education – and plays an especially important role in research, medicine, and health – we took advantage of the REU

program to provide our students with a rich initial grounding in bioethics, both professionally and in a broader sense. A substantial ethics component was critical for at least three reasons. First, students who will be researchers or engineers should be aware of the ethical obligations, hazards, and histories of their discipline, so that their own practice might be guided by this knowledge. Second, because the expanding capabilities of engineering and science (most especially in the biological and medical areas) continue to challenge and transform our society, the engineers and scientists who bring about these innovations need to be aware of these aspects – not only as professionals choosing *what* research goals to pursue, but also as citizens. And lastly, because most technical students do not have the luxury of studying extensively in the humanities, they may not have many opportunities to acquire an ethical perspective elsewhere. These aims cannot be fully addressed in one component of a nine-week summer experience, but our ethics component at least raised the students' awareness of key issues and provided a foundation for later expansion. Rather than concentrate only on traditional research ethics, we explored the ethical issues that permeate the biomedical field in both directions: in its internal practice and its large external impact upon society. These two sides can be approached together by examining the conduct of clinical trials, a topic students find engaging for its real-world relevance.

Students were assigned two papers as part of the ethics component of the summer. The first – following an orientation session on informed consent, the movie *Miss Evers' Boys*, and extensive class discussions – directed students to consider the connections between past ethical violations (notably in Tuskegee) and the formation of particular ethical guidelines and regulations that followed (notably the ethical principles set forth in the *Belmont Report*). The second assignment shifted the focus from historical considerations to the present day, using the debate surrounding the conduct of international drug trials in impoverished nations as an example of a modern ethical gray area for which explicit regulations do not yet apply or are unclear. In this assignment, students were asked to formulate and defend their own position on the subject, in part using the principles which they explored in the initial paper.

We hoped to accomplish at least two things by this technique. First, it emphasized that the existing regulations are not merely irrelevant codifications of common sense ideas, but are vitally necessary to prevent travesties, and in fact were brought about by such violations. Second, focusing on current issues emphasized that while legal ethical guidelines are necessary, they cannot be considered sufficient, or a substitute for independent moral consciousness. In both cases, legal ethical guidelines struggle to keep pace with developments. Without this perspective, historical cases can be seen as merely regrettable examples of a benighted age, with little to teach us today except how bad things used to be. In addition, students were exposed to the founding principles of bioethics, and then asked to apply them in new contexts.

After these structured exercises, the ethics component allowed students to explore current bioethical controversies from the literature. Students gave a short PowerPoint presentation on an issue they found compelling, including their position on it. They covered issues such as embryonic stem cell research, organ markets, genetic testing, and others. After each presentation, the instructor facilitated a brief discussion. Through this three-part structure of the ethics component, students were allowed to address ethical issues they found most relevant or interesting, in addition to learning about foundational cases in bioethics history, and the

principles which guide ethical thinking today. At the same time, they began to develop their own ethical thinking skills; we wanted students to begin to be able to form, evaluate and defend their own ethical responses, as well as understand and appreciate competing view points. These are difficult things to measure accurately, but our concept-map assessments showed substantial improvement in the sophistication of student conceptions of ethics<sup>13</sup>. Moreover, survey data confirmed that students found this ethics exposure to be valuable, unique and relevant.

## **2.5 Communications component**

The research projects, requiring reports at the end of the summer, and the ethics assignments, which employed a “Write to Learn” approach (9) and required papers and presentations, allowed the communications instruction to be fully integrated into the other program requirements. Our goal was to help students acquire greater competency in communication without burdening them with assignments that would detract from their research. In addition, since the ERC was committed to exploring educational methods that improve learning, we wanted to offer communication instruction that did more than simply repeat what students may have learned or can learn in a regular course in technical writing or presentation. Thus, in the VaNTH REU, we worked to meet the challenges related to communication instruction in three ways: first, by tying all communication assignments to the students’ other work in research and ethics; second, by integrating instruction into group discussions that are mostly informal and fun; and finally by targeting skills and activities that can help students start thinking about communication more as experts than novices, thus moving them along a trajectory of knowledge consistent with objectives in many other VaNTH efforts.

Students’ assignments in written and oral communication were presented in a syllabus that integrated research activities, ethics discussions, and communication assignments. These included short oral presentations done through NetMeeting to explain their research projects to each other, the short ethics papers and presentation described above, a written report and abstract about their research for the VaNTH annual report and archives, and a final oral presentation, done through videoconferencing, on their research results and lessons learned from the summer. Students received group instructions and feedback in our weekly teleconferences, but they received individual coaching on slide design and all written work through in-person or online conferences. They also did peer editing. Thus, students were able to revise their communication deliverables and see how communication improves if one approaches it as a process. In addition, since students knew they would be making final presentations to a larger audience at the end of the summer as well as submitting reports to VaNTH, they were writing to real audiences – and thus engaging in the authentic “challenge-based” or “problem-based” instruction that VaNTH advocates because of its pedagogical effectiveness, the same kind of potential for effectiveness that the students were developing in VaNTH content modules.

This approach and our array of assignments also helped students think more like expert engineering and research communicators. In contrast to novice communicators, who focus on learning the rules for specific communication tasks (e.g. what is the “right” way to write an abstract? Are personal pronouns acceptable in a final report?), experts think about larger concepts, such as why they’re writing, who constitutes their audience, and what kind of evidence that audience will find convincing. As a result, they work more with communication strategies



We also recruited members of underrepresented groups by sending our program announcement to the Society of Women Engineers (SWE), the National Society of Black Engineers (NSBE) and the Society of Hispanic Professional Engineers (SHPE) and to the Society for the Advancement of Chicano and Native Americans in Science (SACNAS). Our minority recruiting focused heavily on various Louis Stokes Alliance for Minority Participation (LSAMP) groups. Because of the overlap between LSAMP programs and participating universities in VaNTH, we developed a strong relationship with The University of Texas System LSAMP and the Tennessee LSAMP and have recruited successfully from those programs. We also sent email flyers to the director of each LSAMP program requesting that they share the opportunity with their students. These methods were successful. Our minority applications rose from an average of 15% in the first 5 years of the program to over 40% of the applicant pool in each of the last three years as we implemented the strategy.

Applications were submitted online using a web-based form. In addition to personal and academic information, students provided a description of their reasons for applying (approximate length of 200 words). Applicants were asked to apply for no more than two of the positions listed in the announcement, and to prioritize their choices. Finally, applicants were requested to submit a transcript and to obtain one letter of recommendation in support of their application.

In mid-March we began the selection process. Lists of students who indicated interest in specific research areas were sent to the corresponding faculty mentors. Faculty members then evaluated the applicants and contacted them as necessary. Finally, a “wish list” of applicants was submitted to the coordinators at each site. The candidates listed were evaluated for diversity and replication (so that a particular student was not invited to work on two different projects) before offers of admission were sent. Personal contact with the applicants by the mentor and coordinator was also important at this stage. The recruiting process continued until all available slots were filled.

### **2.7 Enrolled students and demographics**

To date, 94 students have formally gone through the program. A few additional students, paid by funds other than the REU Supplement to VaNTH, have also participated in the full spectrum of activities outlined above. Students have come from a large number of institutions. The recruitment strategies have successfully recruited a group of students that is diverse by gender and race as illustrated in Table 3. Upon entry, 13% had completed the freshman year, 39% had completed the sophomore year, and 48% had completed their junior year.

### **3. Project examples**

Several specific projects that have been done by students in the past few years illustrate the types of projects and what students learn from them. In most cases, these are the students’ own descriptions from their final reports, modified for brevity and consistency.

#### **Project 1: Module on Synaptic Transmission for a Physiology Course - Northwestern**

“We created a module on synaptic transmission for a biomedical engineering neurophysiology class by presenting synaptic transmission in the context of a drug effect. Furthermore, a unique problem-solving, engineering aspect was added to the course material to mimic real-world

	2000	2001	2002	2003	2004	2005	2006	2007	Total	%
Total # Students	8	11	11	11	9	16	16	12	94	
By Gender										
Male	5	5	7	6	4	9	6	6	48	51
Female	3	6	4	5	5	7	10	6	46	49
By Race										
African American	0	1	1	0	0	6	7	5	20	21
Asian	3	0	3	3	4	2	1	1	17	18
Pacific Islanders	0	0	0	0	0	0	0	0	0	0
Hispanic	0	2	1	0	1	1	1	2	8	9
Native American	0	0	0	0	1	0	0	0	1	1
Caucasian	5	8	6	9	4	7	7	4	50	53
Other	0	0	0	0	0	0	0	0	0	0
Underrepresented Minorities	0	3	2	0	2	7	8	7	29	31
By Class after REU completion										
Sophomore	0	0	2	2	0	3	4	1	12	13
Junior	5	5	4	3	3	6	5	6	37	39
Senior	3	6	5	6	6	7	7	5	45	48

applications in the classroom. Much of the early portion of my summer experience was spent learning the subject matter necessary to produce effective teaching materials. Since caffeine acts primarily as an antagonist of adenosine receptors, I had to spend much of my time investigating the physiology of the neuromodulator adenosine. I began to make educational tools on the topic of synapses and caffeine to be utilized by Prof. Troy in his classroom. While there is a fair amount of scientific literature on adenosine and caffeine, there are not many diagrams illustrating the mechanisms of action. Thus, based upon my knowledge, I began making diagrams and culling knowledge on the structure and function of adenosine and subsequently caffeine. Simple pictures made the explanation much easier and allowed me to comprehend whole expanses of material by simply observing a picture. By creating these various diagrams, I was not only able to clarify what I taught to myself, but I was able to see how to impart that knowledge to other students effectively.”

**Project 2: Module on Biomedical Imaging for High School Students - Vanderbilt**

“Recently, there has been much interest among high school AP Physics teachers for teaching tools in medical imaging. Last summer, materials for x-ray imaging were developed and are currently in the process of dissemination. This summer, the focus is on ultrasound and nuclear medicine imaging modalities. These materials cover the basic fundamentals, techniques, applications, and imaging features of each modality. Additionally, since the curriculum is designed for the high school level, it must be affordable; the required materials for an experiment must not cost more than \$25. The tools and resources under development follow the format of the Legacy Cycle, a challenge-based instructional approach that supports the *How People Learn* framework. A grand challenge is introduced, and students research multiple perspectives and perform experiments in order to develop the proficiency to answer the challenge. After an initial run with a small group of high school students, the materials were disseminated to a

select few high school teachers for a larger test run. Finally, they were made available as electronic documents through the internet or on compact discs through the mail.”

### **Project 3: Project on Developing a Computer Simulation of the ECG – Harvard/MIT**

This project was “to develop an electrocardiogram (ECG) computer simulation to assist medical students and bioengineering graduate students in understanding electrical conduction pathways in heart tissue, depolarization and repolarization of heart cells, the relationship between electrodes and the ECG, interpretation of the ECG, and the influence of conduction block on ECG propagation. The simulator is an interactive teaching tool that allows students to visualize and model conduction pathways in cardiac tissue. Students use various paint tools to construct a 2D array of different cardiac cells including excitation, conduction, and contraction. The array of cells can then be stimulated causing the cells to depolarize from their resting potential, followed by repolarization to return to a negative electric potential. This series of events simulates contraction of a portion of the heart. The simulator uses three movable electrodes and leads to create electrocardiograms depicting the electrical activity in the grid of cardiac tissue. This allows students to visualize the relationship between electrode placement and electrocardiogram output. Professors can use this interactive learning tool as part of a Legacy Cycle. For example, before specific lecturing about electrophysiology, a student could be challenged to use the ECG Simulator to replicate three electrocardiograms given by the instructor. The student would use the computer program to paint various cell types throughout the cell grid and watch the output on the electrocardiograms. Without knowledge about an electrocardiogram and electrode placement, the student would have a very difficult time replicating the ECGs. This would set up their interest in a formal lecture that would provide relevant information about generation of the electrocardiogram. The student should then be able to replicate the given electrocardiograms with limited attempts.”

### **Project 4: Project on assessing an HPL structured Transport course - Texas**

“This study evaluates the effectiveness of the HPL (How People Learn)-structured bio-medical transport class at the University of Texas-Austin, developed by Dr. Ken Diller of the VaNTH ERC. The class was designed to increase students’ conceptual knowledge and their ability to transfer knowledge to difficult and unique situations. The data that were used for analysis consisted of past exams taken by students in the HPL structured bio-medical transport class who willingly signed a consent form. In order to code these exams an applicable rubric had to be created that effectively measured the students overall comprehension of the *generate ideas*, *knowledge based*, and *adaptive expertise* questions. Once the rubric was created every question from the three exams had to be carefully coded in order to provide the most valid results. These results will assist in revealing the actual effectiveness of HPL and analyze which students displayed the best comprehension from various aspects i.e. race and gender. This complicated process was made relatively simple as a result of [an] efficient group performance [among two other REU students], Stephanie Rivale (Graduate School mentor), and I [sic]. Each of three questions (*knowledge based*, *adaptive expertise*, and *generate ideas*) were different in their own ways making it very difficult to create one rubric that could be used for all three questions. A rubric was eventually created that could be applied to each question. The coding process along with establishing reliability, and creating a rubric were the main accomplishments of my research this summer. All of that information is now all one database. Stephanie can now statistically

analyze the data. The results from the data analysis will reveal the actual effectiveness of this HPL structured course.”

Some general points about the value of these experiences to both the students and faculty emerge from these examples:

- 1) Students internalized learning science principles and were able to use them effectively to create courseware.
- 2) Students learned bioengineering material at the same time that they developed materials to teach it and learned how to explain it to others. Their explanations illustrate their advanced understanding of communication principles, such as combining text and graphics to explain a concept clearly.
- 3) Students engaged in making choices about what material to present, how to present it effectively, and how to evaluate it in the classroom.
- 4) Students made effective partners for faculty in developing materials, because they appreciated where other students may have difficulty.

#### 4. Assessment

The REU program has been quite successful. The most important evidence of that success is in the student projects themselves, evident from the examples above, which show student mastery of key concepts in bioengineering, pedagogy, and communication. Our students have a strong history of leaving usable curricular modules, techniques, and laboratory exercises for the professors’ use each year. A number of students have been authors of conference papers.

A further analysis of our goal of having students learn about pedagogy and education research was done by reviewing a sample of 14 final reports from the last two years of the program. Ten of these students explicitly explained how HPL concepts and/or the Legacy Cycle impacted their work, two others demonstrated an understanding of education research methods in their analyses of data obtained from classroom assessments of new pedagogies, and another used VaNTH’s learning technology platform and showed an understanding of the importance of formative feedback and adaptive delivery. Only one student did not refer explicitly to any learning concepts.

Exit surveys (Table 4) showed that students were highly satisfied, especially in recent years.

Table 4. Exit survey of REU students from prior years.					
I would recommend program to other students 1=very low; 5=very high					
2001	2002	2003	2004	2005	2006
4.2	4.7	5.0	4.5	4.7	4.7

For some, the REU was a life-changing experience, leading them to choose graduate school and the professoriate as a future career. For others, it confirmed their wish to participate in these careers. Exit surveys identified at least one student in each year who was considering

graduate school after participating in the program but had not done so previously, several who were inspired to become educators at the college or high school level, one who has entered graduate school in education technology, one who changed his plan from MD to MD/PhD, and several per year who confirmed their intention to go to graduate school in BME. It is too early to determine whether the REU students will have long term success in their careers, but the REU impacted many students' career choices.

Using a combination of surveys and concept maps<sup>15</sup>, we collected data on students' knowledge, attitudes, and career plans before and after exposure to our program and methods. Students were asked to produce concept maps of three additional areas of learning associated with the summer program: what makes a good learning experience, what are the most important concepts in technical communication, and what are the most important concepts in bioethics. A study of the use of concept maps for the understanding of ethics and communication concepts was done with VaNTH REU students over several years<sup>13</sup>. This study showed important gains in students' ability to understand ethical decision-making strategies and the complexity of ethical issues in bioengineering. In communication, the study showed substantial growth in two areas of the instruction: their awareness of the multifaceted nature of engineering communication and the importance of writing and presenting with a specific audience in mind.

## **5. Conclusions**

This unique REU program, focusing on education research rather than bioengineering research, has proved to have considerable value for students: it has made them aware of crucial issues in teaching and learning, introduced them to new research methods, and influenced their choice of graduate school and/or career. We found, perhaps surprisingly, that many engineering students greatly enjoyed working in the field of education rather than bioengineering for a summer. It has also been of great benefit in developing tested teaching materials for bioengineering faculty and in helping students grow in their professional thinking and skills in an authentic, carefully mentored summer experience.

The major goals and methods of the program could be offered in other settings and combinations, although complete duplication of the program would require a setting where engineering faculty and learning scientists already interact and engage in education research. The presence of an ERC itself is not necessary, because NSF's Site REU programs do not require a parent grant such as an ERC. Even without preexisting collaborations among the different kinds of experts in the VaNTH program, more students could be engaged by engineering faculty to work with university centers of teaching and learning to help develop material with greater educational effectiveness. Educational components are increasingly a component of NSF CAREER and other awards, and students could be more engaged in these components. Other aspects of the VaNTH REU are completely transferable. We have outlined above ways in which the ethics and communications aspects of our REU program, inspired by VaNTH concepts, could be added to any REU program. Also, more recruitment of under-represented minorities could follow the procedures that were successfully used in the VaNTH REU. More schools could collaborate to offer REU opportunities that allow students to collaborate across campuses.

We believe that the VaNTH REU program was an important part of the overall VaNTH mission, showing how students' summer research could be successfully combined with other educational goals that helped them think more broadly about their career opportunities and the kind of impact they want to make on society.

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