Enhancing Core Competency Learning in an Integrated Summer Research Experience for Bioengineers

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ABSTRACT

In the summer Research Experience for Undergraduates offered by the NSF-sponsored VaNTH Engineering Research Center in Bioengineering, core competency instruction in ethics and communication was integrated into students' research experiences outside of formal courses. This paper describes our instructional approach and presents an initial evaluation of its effectiveness. A simple concept mapping assessment used at the beginning and end of the summer suggests that students made gains in both areas. In ethics, students developed greater awareness of key concepts, such as respect for persons (informed consent), beneficence, justice, integrity, and responsibility. Gains in communication were more modest, but the maps revealed growth in understanding the importance of audience and the multifaceted nature of technical communication. Overall, the study suggests that students can make measurable strides in core competencies without taking formal courses. Future research should consider integrating components of our intervention into other non-credit experiences for engineering undergraduates.

Keywords: REU, concept mapping, communication, ethics

I. INTRODUCTION

In the last decade, engineering schools have renewed efforts to ensure that students receive solid instruction in core competencies such as communication, teamwork, and ethics that cut across engineering disciplines. One impetus for these efforts is the identification of key evaluative criteria in these areas by ABET [1]. Incorporating core competency instruction is a challenge for engineering faculty since the engineering curriculum is already crowded and most engineering faculty members are not trained to provide instruction in these areas.

The NSF-sponsored VaNTH Engineering Research Center (hereafter, VaNTH) [2], a consortium of schools developing curricular material and innovative teaching strategies for bioengineering, is one of several groups investigating ways to meet this challenge [3–6]. VaNTH, which stands for **Va**nderbilt, **N**orthwestern, the University of **T**exas at Austin, and the **H**arvard-MIT Division of Health Sciences and Technology, has been exploring ways to offer core competency instruction in stand-alone courses in ethics and communication and within other courses in the form of short units or educational modules [7–9]. Concurrently, VaNTH researchers have been exploring ways to help students in non-credit settings develop the mindsets and skills in core competency areas that ABET endorses. We focus here on one such non-credit setting, the VaNTH summer Research Experience for Undergraduates (REU), and examine the extent to which modest but deliberate instructional interventions can raise student awareness of key aspects of ethics and technical communication.

Typically, a bioengineering summer internship provides students with a non-credit, hands-on opportunity to learn the content and techniques used in a faculty member's research projects. Exposure to core competencies such as ethics or communication, if offered at all, is not usually systematic but rather incidental to these research experiences. In contrast, the VaNTH program combines students' bioengineering activities with explicit and integrated instruction in ethics and communication, offered in an informal setting, resembling a community of practice [10].

Does this approach work? Can students make significant progress in understanding ethics and communication in bioengineering without studying these topics in conventional classroom settings and being assessed with graded exercises? Moreover, if students do learn, what exactly do they learn? This paper describes our approach to promoting core competency learning in a research-oriented non-credit setting and presents an initial evaluation of its effectiveness. Given the limited time available for core competency aspects of the summer experience, we did not attempt to measure changes in students' actual ethical decision-making or their writing. However, using a simple concept-mapping technique, we assessed growth in students' awareness of key concepts in both areas. Greater awareness of important issues to consider when making ethical decisions or communicating information to others seems likely to enhance the chances of students considering these dimensions when dealing with real ethics and communication problems.

II. Instructional Approach

A. The VaNTH REU Program

As described previously by Hirsch, Bird, and D'Avila, students in the VaNTH REU program come from a variety of backgrounds, majoring primarily in biomedical engineering, but also in mathematics, computer science, and education [11]. Most REU students work on one of the 15 domain projects initially identified by VaNTH as significant areas in bioengineering, such as systems physiology, tissue engineering, biomedical optics, biomedical instrumentation, biomaterials, and biomechanics. Since all VaNTH research is done by interdisciplinary teams, REU students are immersed in a rich experience with domain experts, experts in assessment and learning science, other undergraduates, graduate students, and sometimes industry representatives. REU students have created educational materials for middle, secondary, and higher education programs such as video and audio components of faculty lectures, interactive simulations, and Web sites designed to enhance instruction. Others have developed relational databases used to store and display the taxonomic structure of bioengineering domains. REU students 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.

B. Rationale for Core Competency Instruction

The National Research Council report *How People Learn (HPL)* underlies the VaNTH education effort [12]. Following the recommendations and best practices presented in this report, VaNTH faculty members strive to give REU students meaningful instruction in ethics and communication. This instruction, which is integrated with students' research activities, is designed to be—at least to some extent—"learner-centered," "knowledge-centered," "assessment-centered," and "community-centered." For example, simple concept map assessments at the beginning of the summer promote the learner-centered dimension of the instruction by providing insight into student knowledge about communication and ethics as they begin their internships. This helps instructors design interventions that build on students' prior knowledge and foster a stronger knowledge base. In addition, students work in small groups as a learning community to exchange ideas and give each other feedback on drafts of presentations and papers. As they pursue their research, REU students investigate ethical dilemmas like informed consent that affect various communities, including their own.

Another VaNTH-like dimension of the summer instruction stems from the focus on expertise. In the core competency areas, VaNTH researchers have suggested that experts understand concepts as well as skills and that novices need to be instructed in both [13, 14]. In communication, for example, an expert knows how to write concise, accurate sentences and well-structured paragraphs, but also knows much more than that; the expert is first and foremost familiar with key rhetorical concepts such as audience, purpose and genre. An expert knows that language choices are not simply right or wrong but rather appropriate and effective within a particular discourse community and rhetorical situation. Our integrated approach to core competency instruction aims to help REU students not only enhance their skills in writing, oral communication, and ethical decision-making, but also develop fuller, more nuanced, and more accurate working mental models of these areas.

C. Implementation

The structure of the summer core competency program has three basic elements: an initial orientation at Vanderbilt University; a jointly run, virtual and real ethics and communication mini-course; and a final, teleconferenced presentation.

1) Initial Orientation: In each of three years (2002–2004), the REU students met as a large group for an initial orientation that coincided with the NSF ERC site visit. They met their project mentors and the faculty for ethics and communication, attended VaNTH presentations and the VaNTH poster fair, engaged in several assessment activities (such as concept mapping for ethics and communication), took field trips to see bioengineering in action, and bonded as a group by sharing meals and free time together. In summer 2003, for example, students met with their ethics and communication instructors to discuss their initial ideas about the nature of ethics in BME and about what constitutes technical writing. At the end of the orientation, students left for the campus where they spent the rest of the summer.

2) A Mini-Course: Once the students were at their different sites, they stayed in touch by (a) meeting in their small groups at each campus; (b) using a courseware package called Prometheus, which resembles the more widely used course management system called Blackboard and allows for course materials (e.g., assigned readings, PowerPoint lectures, worksheets) to be posted on-line and for students to hold on-line discussions; and (c) having weekly teleconference sessions coordinated by NetMeeting. Assignments included a range of writing experiences (e.g., brief reports on interviews with mentors, descriptions of equipment or procedures, explanations of ethical concepts) coordinated with each student's research focus and also with the ethics curriculum. Instruction involved feedback, reflection, and conversation tied to reading, writing, and oral presentation assignments.

A major project for each REU student in 2002 and 2003 was to write and revise a paper focusing on an ethical issue related to his or her research. Students began by looking at the Belmont Report (the foundation for the U.S. government's regulations governing research with human subjects) and the VaNTH ethics taxonomy [15, 16]. Each student then worked with his or her mentor to identify an ethical issue related to his or her research. For example, a student working in tissue engineering wrote about whether animals should be used in labs designed for undergraduates; a student working on the "I, Bio" middle school science module wrote about whether students participating in VaNTH modules are being fully respected as research subjects; a third student, working on microbial kinetics, wrote about purity levels in penicillin production—is it ethical to produce penicillin at a level of purity stipulated by the federal government if that level is below what we know produces maximum effectiveness?

As students did lab and library research, read the Belmont Report, and interviewed their professors, they explored issues of bias in research studies, equity in resource allocation, and ownership of intellectual property. A key feature of the summer program was their weekly teleconferenced discussion session. Faculty from ethics, communication, and learning science took turns facilitating some of these discussions, while students, working in small groups across sites, facilitated others. In addition, small groups of faculty and students at each site met weekly to discuss their ideas. Finally, each student explored his or her issue in a detailed 8–10 page paper, received feedback from both ethics and communication experts, and then prepared a final report and slide presentation.

In essence, the ethics instruction used the case study approach recommended by many experts in ethics education [17–19]. Students focused on real situations in which ethical questions can arise and to which the ethical principles covered in their readings and presented by the ethics expert could be applied. They discussed the situations with both peers and experts. What distinguished our approach was that the cases explored by REU students did not come from textbooks or Web pages [e.g., 20–22]. Instead, the research projects were ones in which the students themselves were directly involved, and the specific aspects of these projects on which they focused in their papers were ones that the students themselves had identified as ethically problematic.

In addition, the ethics instruction and the communications instruction took place simultaneously. In the weekly teleconferences or on-site meetings, students were asked to think about large ideas related to communication, such as having a communication strategy that relates purpose and subject matter to audience and tone. Our focus was not so much on skills development as it was on rhetorical strategy: what kinds of arguments would they need to make to a specific audience, such as a pharmaceutical company, in order to be convincing about a particular topic, such as the purity level of penicillin? In our community of practice, we tried to articulate the way that experts read and evaluate papers, looking not so much at grammatical and mechanical correctness (which professionals take for granted), but at the arguments and reasoning that the writer was bringing to bear on his or her thesis.

Although students communicated individually with the communications instructor, the key pedagogical vehicle was the weekly group meeting. Here students were able to see how the communications concepts they were exploring in their papers applied to other communications tasks as well. For example, we stressed the importance of audience as we evaluated the slides that students produced for different kinds of teleconferences. Were they designing slides to introduce themselves and their projects to each other, in which case, it was appropriate—and amusing—to show a photograph of themselves in formal attire from a senior prom, or were they developing slides for their final teleconferenced presentations to VaNTH faculty and administrators, who would expect a professional looking photograph and an introductory slide that focused more on education and experience than on personality? The instructional method was more limited and at the same time more focused than in most Writing Across the Curriculum or Writing Within the Disciplines interventions [23]; our key pedagogical method was conversation.

However, since we also wanted students to develop greater awareness of the importance of visual communication in engineering, we presented key concepts visually as well as verbally. For example, students in both years were shown the diagram in Figure 1 and asked to think of a communication framework as a "rhetorical square" in which the key concept on each side—audience, tone, purpose, or message—is related dynamically to all of the other key concepts. In the teleconferences, we repeatedly noted that technical communication is "multifaceted'; although most people think of technical communication as a form of writing, engineers usually combine written communication with graphs, diagrams, data, and equations they present through technology, and often across distances, as we were forced to do. Students' technical communication activities reflected all these facets. As the audience for these weekly discussions, students could experience personally the power of a well-designed slide and effective visual and verbal communication.

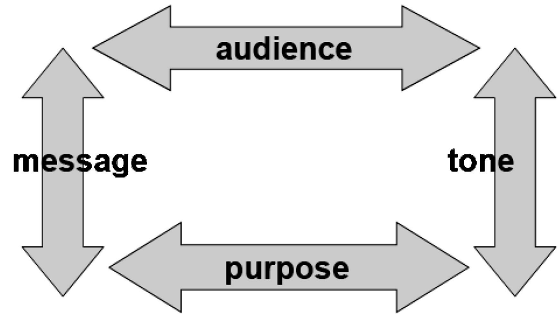

Figure 1. Rhetorical framework or "square" that experts use to plan communication.

3) A Final Presentation Event: The summer experience culminated in a three-hour cross-site event in which students summarized their research and discussed what they were taking away from the REU experience from all three areas: biomedical engineering, ethics, and communication. Each student prepared a 10-minute PowerPoint presentation for the event. He or she first used those slides in a practice presentation and received feedback from domain and core competency experts, and then gave a final presentation in a teleconferenced setting to conclude his or her summer work.

III. Assessment of Student Learning

A. Concept Maps

Informal comments from both site administrators and instructors suggested a marked improvement in REU students' presentations and in their awareness of ethical issues. For example, the ethics instructor from 2002 and 2003 claimed that students "began to recognize both the variety and complexity of the ethical aspects" of their work [24]. Additionally, in post-program questionnaires students said that they became "somewhat" or "a great deal" more aware of ethical issues in their classes when they returned to school in the fall and that they felt more prepared for ethical problems they may encounter in their professional lives. In 2001, two students attended the ASEE national meeting, where they described the impact of their REU experiences on their thinking and their course selection and college activities after the summer. One had done historical research on human subjects cases, focusing particularly on whether it is ethical to do research with human subjects in the third world. She claimed that the summer experience not only increased her awareness of ethics in bioengineering, but that she was able to impart that awareness to others because she designed and presented an ethics module based on her research when she returned to school in the fall [11]. Similarly, other students reported anecdotally that their technical communication experience improved their writing and especially helped improve their presentation skills. They began to see how biomedical engineering, communication, and ethics interact.

Consistent with the VaNTH mission and assessment-based approach, we wanted to obtain a more objective picture of student core competency learning in the REU program. To supplement the anecdotal reports, we began to use a simplified form of concept map assessment.

Concept maps, or visual representations of thinking about a domain, use labeled nodes to indicate relevant concepts and labeled directional lines to connect the concepts and indicate perceived relationships between them. Many also use a hierarchical structure, resembling an organization chart. Concept maps can be used in various ways in educational settings—as a tool for curriculum planning, in instruction, and in assessment [25–27]. In using concept maps as an assessment tool, various map characteristics can be considered, including both structural and content elements. Two key structural elements are the numbers of nodes and lines. An increase in nodes and lines is likely to reflect an awareness of more concepts relevant to the domain depicted. Research has demonstrated an increase over time in the number of nodes and lines that students include in concept maps, thus providing evidence of learning [27, 28]. Another structural characteristic of concept maps is the density, or interconnectedness, of a map. An increase in interconnectedness of nodes can be viewed as another index of intellectual growth. As Novak and Gowan have noted, cross links between map segments can indicate a more integrated understanding of an area [29].

Analysis of the content of concept maps can include inspection of the labels used for the nodes and lines, as well as the nature and correctness of propositions formed by the connection of labeled nodes by labeled lines [30, 31]. Alternatively, holistic approaches can be used to assess overall map quality [32]. Because concept maps make the structure of student knowledge explicit, they can be useful for diagnosing and correcting students' misconceptions and for creating a touchstone for discussion of key concepts and their interrelationships [33].

Since VaNTH researchers were already using concept maps successfully to capture student learning in courses, notably in engineering design [34, 27], we decided to extend concept map assessment to the REU experience. We strove for an approach that would yield simple maps appropriate to the short time available for orienting summer students to concept mapping procedures and for working with the students; in addition, we wanted a method that would not be time-consuming to administer or to score [34].

Our general approach was to look for the presence or absence of key node labels and to compare labels included in student maps to those included in maps drawn by experts.

B. Method

1) Participants: Participants in our assessment were all students who took part in the VaNTH REU program in summer 2002 and summer 2003. Only students who completed concept maps both at the beginning and the end of the summer were included in the analyses of map structure and content. This included 20 students for the communication maps and 19 students for the ethics maps. Due to the small sample sizes, data for the 2002 and 2003 cohorts were combined for all analyses.

2) Procedure: We asked REU students to draw concept maps at the beginning and the end of their internships. In a group meeting at their initial orientation REU students were given written and oral instructions about how to build a concept map, plus several examples of maps. On two consecutive days of their orientation, they were asked to individually construct maps showing the "10–20 most important concepts in bioengineering ethics" and the relationships among them, and another showing the "10–20 most important concepts in technical communication" and the relationships among them. No concept mapping was done again as part of the REU program until the end of the summer (and nothing suggests that students were interested in doing any concept mapping on their own). At the end of the summer experience, they were again asked to draw maps depicting key concepts in bioengineering ethics and in technical communication. Students were given the written instructions and examples, but instead of meeting as a group were asked to complete the maps on their own at their individual VaNTH sites. Our intention was to assess change in students' thinking about professional ethics and technical communication—and to see specifically whether they gained a breadth of knowledge and perspective that resembled that of expert communicators or ethical decision-makers by the end of the summer. Given the informal nature of the summer instruction, we did not anticipate big changes. Nonetheless, we hoped to show that students gained awareness of ideas and information that they had not considered before and thus developed a stronger conceptual base for their core competency achievement in the future.

3) Concept Map Scoring: Scoring of maps was done by a pair of raters in ethics and a second pair in communication. In most cases, raters were unaware of whether each map was created before or after the intervention, and there was no evidence to suggest that knowledge about time (time 1 versus time 2) made a difference in the analysis. Raters coded both structural elements (number of nodes and lines in each map) and content elements (the presence or absence of key concepts).

To address inter-rater reliability for the ethics concept maps, the second rater scored a random sample of 13 of the 38 maps. The two raters agreed on the number of nodes in each map. For number of lines, they agreed for 11 of the 13 maps; the intra-class correlation between their ratings was 0.995 (range = 0 to 1.00). In addition, the two raters almost agreed on the presence or absence of each key concept coded; their overall level of agreement for concepts was 99 percent. Given the high level of agreement, the remaining ethics maps were scored by only one rater. For communication concept maps, there was also a high degree of agreement between the two coders. For number of lines, the intra-class correlation was 0.995. For the total number of nodes, this correlation was similarly high (0.994). For communication concepts, reliability was calculated by tabulating the number of observations that were agreed upon by both coders, and dividing that by the total number of observations. Overall, both coders agreed on 79 percent of observations. Some variability existed between categories, with reliability at its lowest for the category of "channel/media/technology" (75 percent), and highest for the categories of "purpose" and "audience" (83 percent).

C. Results: Ethics Concept Maps

1) Structural Variables: Concept maps drawn at the beginning of the summer (time 1) and the end of the summer (time 2) were compared on three structural variables: number of nodes, number of lines, and a measure of density of the map, the line/node ratio. Higher line/note ratios indicate greater interconnectedness among the included concepts. All comparisons were done using paired t-tests and an alpha level of 0.05.

Concept maps drawn by students at the end of their summer experience had significantly more nodes than those drawn at the beginning of the summer. The mean number of nodes at time 1 was

11.21 ($SD = 3.75$), and the mean at time 2 was 17.79 ($SD = 5.71$), $t(18) = 4.77, p < 0.001$.

Concept maps drawn by students at the end of their summer experience also had significantly more lines than those drawn at the beginning of the summer. The mean number of lines at time 1 was 12.74 ($SD = 5.30$), and the mean at time 2 was 19.16 ($SD = 7.37$), $t(18) = 3.33, p < 0.004$.

Time 1 and time 2 maps did not differ in their line/node density. Those drawn at the beginning of the summer had a mean line/node ratio of 1.12 ($SD = 0.26$) and those drawn at time 2 had a mean line/node ratio of 1.06 ($SD = 0.16$), $t(18) = 0.94, p = 0.359$.

2) Content Variables: Concept maps were also scored to see whether they incorporated key concepts included in the ethics instruction. The ethics expert who coordinated the ethics component of the summer experience prepared a map to reflect her own view of the domain. Each student map was then inspected to see whether each of these key concepts was present or absent. Three of these key concepts were the three key principles identified in the U.S. government's Belmont Report as those underlying guidelines for the ethical treatment of human subjects [11]. The principles and their operational definitions were as follows:

- *Respect for persons*—This principle was considered present if the concept map included the term *respect* and/or if it included a mention of *informed consent* or *consent*. As discussed in the Belmont Report, the main application of respect to human subjects research is that people should, to the extent possible, be considered autonomous agents who can freely choose whether or not to participate.
- *Beneficence*—This principle was considered present if the concept map included the term *beneficence* and/or if it included a mention of *harms*, *costs* or *risks* and *gains* or *benefits*.
- *Justice*—This principle was considered present if the concept map included the term *justice* and/or if it included a mention of *issues related to fairness of subject selection*. According to the Belmont Report, the principle of justice leads to a consideration of fairness in the selection of participants for research.

Maps were also coded for the present or absence of two additional concepts which, along with the Belmont principles, were top-level concepts in the expert's map. These were:

- *Integrity*—This concept was considered present if the student included the word *integrity* or a word such as *truth* or *honesty*.
- *Responsibility*—This concept was considered present if the student included the word *responsible* or *responsibility* in his or her map.

Two other concepts were included in the coding scheme following an initial inspection of the concept maps (with time 1/time 2 information removed). These concepts seemed to be present in several maps, but not all. We decided to see if the presence or absence of these concepts was related to whether the map was drawn at the beginning or end of the summer. The concepts were:

- *Credit for work*—This concept was considered present if the student mentioned anything related to giving, or not giving, proper credit for contributions to a project. Relevant terms included *plagiarism* and *authorship*.
- *Right vs. wrong*—Naïve definitions of ethics often include the notion of right and wrong behaviors. Maps were coded for the presence or absence of the terms *right* and *wrong* to see if use of these terms decreased as students' thinking about ethics became more complex.

Table 1 presents the percentage of students mentioning each ethics concept at time 1 and at time 2. McNemar's change test was used to assess whether the proportion of students mentioning each concept at the end of the summer experience was significantly greater than the proportion doing so at the beginning of the summer. This test is particularly well suited for capturing change over time when participants serve as their own comparison group, yet data are categorical. A conceptual equivalent for continuous data would be the paired *t*-test. The Yates correction for continuity was employed to address concerns over the small number of subjects per cell. This method aids in reducing the instability of data when few cases are used for analysis [35]. For all analyses, alpha = 0.05.

Overall, students showed a significant increase in their inclusion of top-level concepts (i.e., concepts in the top level of the expert's concept map). Students included a mean of 0.37 ($SD = 0.60$) of the five concepts at time 1 and 2.58 ($SD = 1.30$) at time 2, $t(18) = 8.15$, $p < 0.001$. The change was statistically significant for all three Belmont code concepts (respect for persons, beneficence, and justice), as well as for integrity and for credit for work. The change in responsibility was not significant; few students mentioned this concept at either time. As anticipated, while all other concepts were mentioned more often at time 2 than at time 1, the proportion of students mentioning right vs. wrong decreased from the beginning to the end of the summer; this difference approached statistical significance ($p = 0.13$).

Concept	Pretest	Post-Test	McNemar Test (χ^2)	McNemar Test (p)
Respect for persons	0.05	0.79	12.07	< 0.001*
Beneficence	0.16	0.58	4.90	0.026*
Justice	0.00	0.68	11.08	< 0.001*
Integrity	0.11	0.42	4.17	0.041*
Responsibility	0.05	0.11	0	1.000
Credit for work	0.05	0.37	4.17	0.041*
Right vs. wrong	0.37	0.11	2.29	0.130

Table 1. Frequency of inclusion of ethics concepts in students' concept maps before and after the summer REU experience.

Typical differences between time 1 and time 2 maps are illustrated by Figures 2 and 3. Figure 2 shows a map drawn by one REU student at the beginning of the summer to illustrate key concepts in bioethics. This map reflects no specific understanding of ethics in bioengineering or historical perspective. Instead, with its prominent focus on "right vs. wrong," it illustrates a novice's "black and white" understanding of ethics rather than an expert's deeper understanding. Figure 3 shows the same student's map from the end of the summer. This map is much richer and more nuanced than the earlier map. It includes the three Belmont code principles, as well as other key principles identified by the ethics expert, and it also indicates awareness of how principles are put into practice, e.g., through consent forms for research participants.

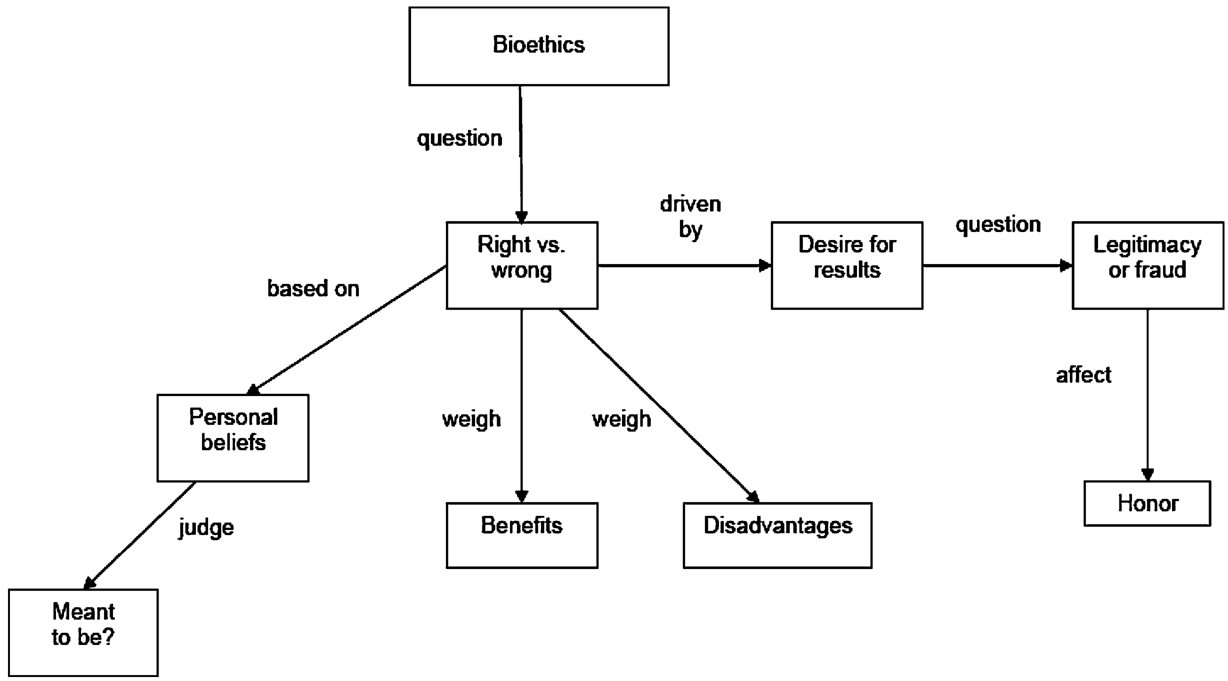

Figure 2. Student concept map depicting bioengineering ethics, drawn at the beginning of the summer experience.

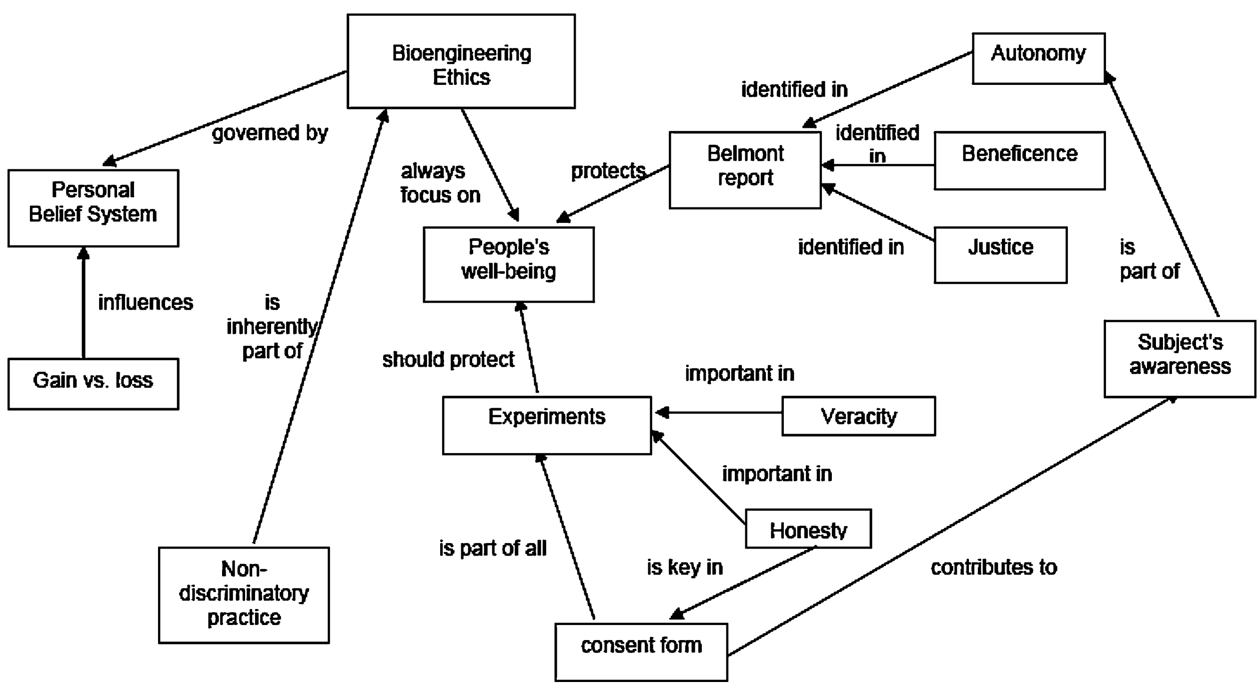

Figure 3. Ethics concept map drawn by the same student at the end of the summer.

D. Results: Communications Concept Maps

1) Structural Variables: As above, concept maps drawn at the beginning of the summer (time 1) and the end of the summer (time 2) were compared on three structural variables: number of nodes, number of lines, and a measure of density of the map: the line/node ratio. All comparisons were done using paired *t*-tests and an alpha level of 0.05.

Concept maps drawn by students at the end of their summer experience had no more nodes than those drawn at the beginning of the summer. The mean number of nodes at time 1 was 14.83 ($SD = 3.1$), and the mean at time 2 was 15.17 ($SD = 3.53$), $t(19) = 0.39, p = 0.70$.

Concept maps drawn by students at the end of their summer experience also did not differ from those drawn at the beginning of the summer when considering the number of lines. The mean number of lines at time 1 was 15.83 ($SD = 3.6$), and the mean at time 2 was 16.87 ($SD = 5.0$), $t(19) = 0.953, p = 0.351$.

Time 1 and time 2 maps did not differ in their line/node density. Those drawn at the beginning of the summer had a mean line/node ratio of 1.07 ($SD = 0.2$) and those drawn at time 2 had a mean line/node ratio of 1.09 ($SD = 0.13$), $t(19) = 0.506, p = 0.618$.

2) Content variables: Concept maps were also scored to see whether they incorporated key concepts included in the communication training. Six key concepts were investigated.

- The *multifaceted nature of technical communication*—This concept was considered to be present in a map if students referred to three of the following facets of technical communication, written, oral, graphical, mathematical, and interpersonal, or if they articulated one or more of these and clearly implied others by referring to genres like "presentations" and "reports" or tools such as PowerPoint.
- Four concepts from the communication framework: *purpose, audience, persona* (tone), or *message* (content)—These were considered to be present if they were named directly. In addition, the term *style* was considered an indicator of persona or tone, and *knowledge* was considered an indicator of message.
- *Technology* or *channel choice*—This concept was considered present if these words were used directly, if the map referred to *media*, or if a variety of technologies were listed.

Table 2 presents the percentage of students mentioning each concept before and after the REU experience. To simplify the analysis, only data from coder 1 were used. However, analysis of data generated by coder 2 yielded the same results. McNemar's change test was again used to assess whether the proportion of students mentioning each concept at the end of the summerexperience was significantly greater than the proportion doing so at the beginning of the summer. The Yates correction for continuity was employed, and alpha = 0.05 for all analyses.

Comparison of time 1 and time 2 maps indicated that students at the end of the summermentioned significantly more key concepts than those at the beginning of the summer. The mean number of concepts mentioned at the beginning of the summer was 2.10 ($SD = 1.02$). The mean number of concepts mentioned at the end of the summer was 3.65 ($SD = 1.04$), $t(18) = 6.60, p < 0.001$. Two concepts, *multifaceted* and *audience*, were mentioned significantly more frequently after the REU experience than before, and all except one, *purpose*, showed positive trends.

Figures 4 and 5 illustrate the distinction between the lack of growth in absolute number of concepts as compared to growth in understanding; the figures show pre- and post-course communication concept maps from the same student. While there are actually more nodes and lines in the pre-course map, the content is repetitive and uninformed. Almost everything about the student's understanding of technical communication focused on using technology for distance communication, which is a very narrow understanding of technical communication and one that demonstrates misunderstanding by focusing exclusively on the media used and the importance of distance communication rather than on the rhetorical strategy, technical content or message. In contrast, the post-course map is a concise representation of major concepts related to communication in general and technical communication in particular: purpose, audience, tone, genre, media, etc. In addition, in the post-course map the students' "propositions" are more meaningful and present a more coherent overall picture. Thus, this map displays a much deeper understanding of technical communication as a socially and professionally situated activity.

IV. Discussion

Our results suggest that students in the VaNTH REU program expanded their knowledge in both ethics and communications. Students included more key concepts identified by experts in their later maps than in maps they constructed at the start of the summer. This suggests that students can make meaningful, measurable strides in core competency mastery by participating actively in a

Concept	Pretest	Post-Test	McNemar Test (χ^2)	McNemar Test (p)
Multifaceted	0.55	0.95	4.9	0.021*
Purpose	0.25	0.25	0	1.000
Audience	0.35	0.90	9.09	0.001*
Message/Content	0.40	0.65	1.45	0.227
Persona/Tone	0.05	0.25	1.50	0.219
Technology/Channel	0.50	0.65	0.57	0.453

Table 2. Frequency of inclusion of communications concepts in students' concept maps before and after the summer REU experience.

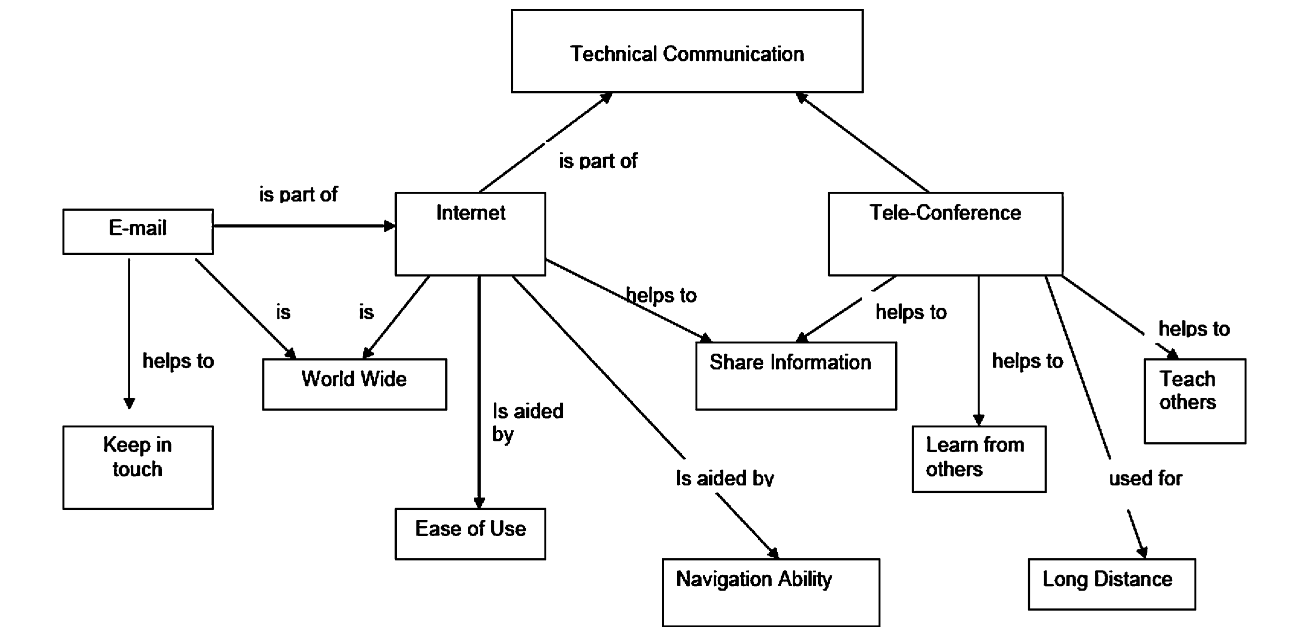

Figure 4. Student concept map depicting technical communication, drawn at the beginning of the summer experience.

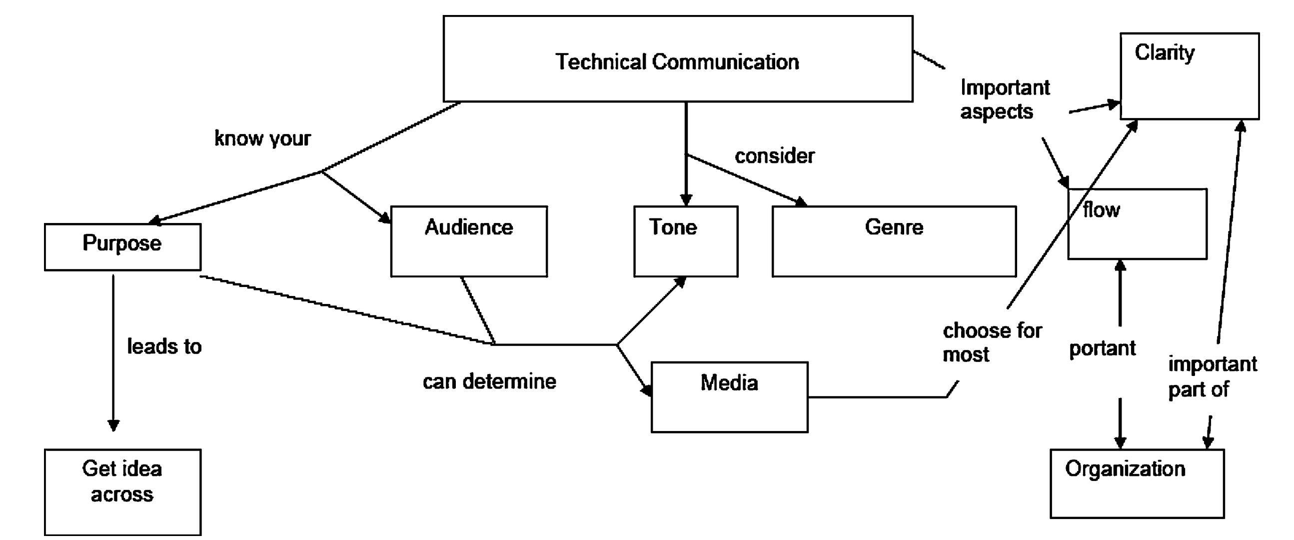

Figure 5. Communication concept map drawn by the same student at the end of the summer.

community of practice without taking formal courses. However, the data also point to important differences in how to think about the teaching and assessment of ethics versus communication.

In ethics, students included significantly more concepts overall (i.e., more nodes) and also more key "expert" concepts in their later concept maps than in their earlier ones. This suggests a greater complexity of thinking about bioengineering ethics and an awareness of more components and perspectives, including those considered most important by ethics experts. The marginal decrease in students' reference to "right vs. wrong" is consistent with their greater knowledge and insight. The movement from a simpler "right vs. wrong" perspective to a focus on relevant ethical principles parallels the move from conventional to post-conventional thinking in Kohlberg's theory of moral development [36].

Our findings with respect to ethics suggest progress on at least two of the four outcomes identified by Davis as desirable outcomes of ethics education for engineering students: "increased ethical sensitivity" and "increased knowledge of relevant standards of conduct" [3]. Granted, students' increased awareness of these ethical areas is no guarantee of in-depth understanding or of their ability to apply their knowledge effectively in ethical decision-making. However, it would seem to be a necessary prerequisite for their using some of these concepts in their own decision-making in the future. The fact that, at the end of the summer, students were coming up with ethical concepts that had not occurred to them at the beginning also helps to explain students' enthusiasm for the ethics dimension of the program and their statements about their increased understanding in informal discussions and surveys.

The pattern of change in communication differs from that in ethics. There was not a significant increase in the number of nodes and lines in the students' pre- and post-course maps. This may, in part, stem from the fact that students enter their summer internships with more knowledge and experience in communication and even technical communication than they do in ethics. All students study writing from the time they are young, and since the REU students are upperclassmen, it would not be unusual for them to have taken additional writing courses, even technical writing, in college. As Chi and Roscoe note, students never enter a learning situation with a "blank slate" although they may be missing information, or they may have "naïve knowledge" of a subject that is incorrect and acts to impede deeper understanding [37]. Thus, students do not enter the summer as novices in writing in the same way that they are novices in formal, analytic thinking about ethics.

This analysis is supported by the fact that the mean number of nodes and lines observed at pre-test was greater for the communication maps than for the ethics maps. Students started the summer identifying more ideas related to communication than related to ethics. In preparing their initial communication concept maps, students were not at a loss for something to say, but they did not include the concepts considered most important to experts and they failed to structure their knowledge in an expert-like, meaningful way.

When one looks at content changes in the communication maps, one sees significant growth in two key areas that the instruction emphasized: the multifaceted nature of technical communication and the understanding of audience, one of the cornerstones of the rhetorical framework. These were areas that were stressed in the teleconferenced discussions and especially in the planning of the final presentations, where the writing and design of final slides showed substantial reconsideration of audience needs. In addition, the concept map data show positive trends for other concepts judged as important by experts. The change in communication maps, then, is not in the absolute quantity of concepts reported (numbers of nodes and lines) but in the sophistication and quality of concepts.

In neither ethics maps nor communication maps did we find an increase in map density (the line-to-node ratio). This is not surprising, given the comparable increases in numbers of lines and nodes for the ethics maps, and the lack of increase of either type for the communication maps. The lack of increase in density suggests that students' recognition of the interconnectedness of concepts did not increase. This may reflect the limited nature of our intervention, given the emphasis on hands-on research activities in the REU program. For example, the different key concepts in ethics were, in fact, presented as separate dimensions, and most students focused on only one or two dimensions in their written work and presentations.

V. Conclusion

Our simplified concept mapping technique enabled us to track changes in students' understanding, as well as areas in which substantial change did not occur. As we learn more about REU students' starting and ending points in ethics and communication, we can plan more targeted interventions. For example, since the data show that REU students learn more about audience than purpose by the end of the summer, we are planning to give them more assignments with different purposes in 2005. Instead of writing one, longer research paper, which is a genre they know well from school, we are moving toward having students write more short documents—such as abstracts for different audiences and a final report that summarizes their summer's work for VaNTH administrators and NSF reviewers.

We can also plan more targeted assessments. For example, concept mapping appears to work well for capturing students' gains in concepts about ethics and communication, but it is not as good for measuring their skills or their ability to apply what they have learned. Future work should compare concept mapping performance to assessments of students' ability to apply relevant concepts as they reason about ethical and communication problems.

Our work has broader implications for how to integrate core competency instruction into the regular engineering curriculum. In the case of ethics, students need exposure to principles and procedures for ethical decision-making and, if possible, opportunities to apply them. In communication, students need similar opportunities to learn and apply the concepts experts take for granted—that a piece of writing or a presentation has to be suited to its audience and purpose and well tailored to its media or channel. Many schools, using the approaches fostered by Writing Across the Curriculum and related movements, have exploited opportunities in laboratory and design courses to improve students' skills in core competency areas. We applaud these efforts and expect them to continue. But we also advocate increased efforts to promote core competency awareness and learning in non-credit settings. Our attempts to integrate core competency instruction with research experiences suggest that meaningful learning can take place in such settings. This implies that faculty members who supervise student researchers in independent study can also guide their students toward documents like the Belmont Report and help them examine and reflect on the ethical and communication dimensions of design and research projects in which they themselves are actively engaged. Similarly, faculty who supervise students in group settings such as design competitions can create discussion groups that function as communities of practice to foster greater awareness of ethics and communication in engineering. Future research should focus on identifying and strengthening key features of the VaNTH REU program that contribute to student gains in core competency areas, as well as on identifying ways in which similar interventions can be integrated more broadly into the experiences of engineering students.

Acknowledgements

This work was supported primarily by the Engineering Research Centers Program of the National Science Foundation under Award Number EEC-9876363. We are grateful to the NSF as well as to VaNTH faculty who helped to develop the integrated REU program: Stephanie Bird, Mark D'Avila, and Jean Alley. We are also indebted to our second coders for the concept map analysis: Katherine Linsenmeier and Emily Wood.

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