Redefining Communication Education for Engineers: How the NSF/VaNTH ERC is Experimenting with a New Approach

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I. Introduction

Engineering schools across the country have offered communication courses for more than 20 years, yet industry representatives continue to call for engineers who can communicate more effectively. EC 2000 lists communication as a key competency for engineers, and engineering faculty concur; yet engineering undergraduates too often see their communication requirements simply as "busywork" that they must complete in order to graduate. What accounts for these discrepancies, and what can we, as engineering educators, do to help students become more skilled communicators and better understand the role that communication plays in engineering?

One reason that many students fail to recognize the importance of communication may be that communication is generally treated as a set of skills that students are supposed to acquire outside of engineering—in composition, technical writing, or public speaking courses. Students see no relation between communication and their genuine engineering work, such as solving equations, modeling processes or doing product design. Although widespread, this approach to communication pedagogy is criticized by many educators in composition, speech, and the learning sciences. In these fields, proponents of "integrated" education remind us that writing and speaking are more than a set of skills, that good communication instruction, like other effective instruction, should be firmly grounded and "contextualized" in authentic intellectual activity[1].

Responding to these ideas, engineering schools have started to experiment with innovative collaborative approaches to communication instruction, especially at the freshman and sophomore levels. As noted in a recent article in *ASEE Prism,* "Engineering schools across the nation are forging new connections with English, speech, and philosophy departments that allow students to study communication, teamwork, and ethics" within newly "reshaped" engineering curricula[2]. These new freshman and sophomore programs have important implications for improving engineering communication pedagogy in upper level courses and the engineering majors.

One group that is looking carefully at these implications is the VaNTH Engineering Research Center (ERC) in Bioengineering Educational Technologies. The Center is a cooperative effort among Vanderbilt, Northwestern, Texas, and the Harvard/MIT division of Health Sciences and Technology (i.e.VaNTH) in collaboration with the National Science Foundation (NSF). At Northwestern University in particular, VaNTH leaders are exploring the ways in which communication functions as an essential core competency in the bioengineering domains. We are also exploring strategies for improving the communication competencies of bioengineering students by integrating communication instruction into innovative, upper-level instructional modules focusing on specific bioengineering domains[3].

In this paper we describe how our efforts are working at Northwestern, where the VaNTH module writers can build upon a successful approach for integrated communication instruction in an innovative freshman course, Engineering Design and Communication. Specifically, we define the approach used in the freshman year, explain the arguments for its success, and review the challenge of adapting it to VaNTH modules aimed at upperclass bioengineering students across the country. We contend that integrating communication instruction into bioengineering course modules has the potential to help students make significant gains in their communication skills. However, we also note that modular instruction poses a number of special difficulties that must be overcome in order to realize those gains.

II. Integrated communication instruction: a new paradigm in engineering communication pedagogy

Traditional approaches to communication instruction in engineering

Communication has always been considered an important, if subordinate, skill for engineers. Until the early 90s, two paradigms for teaching engineers to write dominated the pedagogical scene. In the first model, engineering students were required to take stand-alone courses in composition or technical writing, generally offered by faculty in English departments or at least trained in English composition. The theory was that students are best taught writing by experts in the field and that once students have a good foundation in writing, they can build on that foundation in their majors. For years Northwestern University followed this approach; engineering freshman and sophomores fulfilled a writing requirement by taking English courses in basic or intermediate composition.

In the second model, which surfaced in the 1970s with the Writing Across the Curriculum Movement (WAC), students received help with their writing in conventional subject matter courses in engineering. WAC courses were supposed to help students see that writing is an integral part of engineering and thus be better able to apply general writing principles and rules to their special fields. This approach offered a genuine advance in some successful WAC programs, but many WAC programs were a disappointment[4]. English teachers or graduate students simply functioned as editors for papers assigned by engineering professors. Ironically, this approach reinforced the mistaken ideas about writing that WAC was intended to dispel, that is, that writing is just a set of skills that can be taught separately from intellectual activity and has more to do with spelling and usage than with professional effectiveness. Typically, in WAC programs, communication faculty did not set course goals, write assignments, influence the budget (if there was one), or determine final grades. Not surprisingly, then, they had little credibility with their students and were disappointed with the outcomes of their teaching. Neither stand-alone courses nor WAC courses quieted the call from engineering for better, more effective communicators[5].

A new paradigm: the integrated approach used in one freshman course

In the 1990s, a new and more promising approach to engineering communication pedagogy—one of genuine collaboration--has been emerging. In this paradigm, engineering and communication experts work together to develop a curriculum that blends engineering and communication instruction and leverages the synergies between the two fields to help students learn more about each than if they studied each separately. The emergence of collaborative programs reflects a number of changes in academia over the last decade: an increased emphasis on creative problem-solving in engineering; conceptual advances in other fields about how people learn; and institutional advances, such as greater support in many universities for interdisciplinary, cross-school collaboration. Northwestern University switched to this approach in a major reform of its undergraduate engineering curriculum: as part of its "Engineering First" program[6], it required freshman to take a new course called Engineering Design and Communication (EDC).

In this course, taught over two quarters, approximately 380 students in 24 sections study the design process along with the communication process, while working on conceptual design projects for real clients [7,8,9]. In the first quarter, teams design a variety of World Wide Web projects for local clients at the university or in the community. In the second quarter, students work on projects from a variety of disciplines, using the design process once again to meet the needs of a new client who may be from within the university, the community, or local industry. For example, students have designed a wheelchair for long-distance recreational use, a hidden radio antenna for police cars, a wind-resistant umbrella for children, and a feeding device for a child with familiar disautonomia.

Every section of EDC is team-taught by an engineering instructor from the school of engineering and a communication instructor from the college of arts and sciences. A core committee of faculty from both schools plans the lectures, prepares all course assignments, establishes grading criteria, etc. Students receive substantial coaching on all their work from both sets of faculty. Equally important, in EDC, every communication deliverable is grounded in the engineering design process. Instead of writing essays, papers, and exams, students write to faculty and clients to communicate important information about their projects: for example, they write mission statements, report on client meetings, synthesize the results of research, prepare progress reports, and create slides for PowerPoint presentations. Thus, as a communication course, EDC sends a strong, clear message to students: communication is an integral part of the design enterprise, not merely a superficial matter of editing. Clear communication advances creative problem-solving, the heart of engineering design.

Moreover, students in EDC—and faculty too—see that communication in engineering is a multifaceted activity. Engineering communication combines written, oral, interpersonal, graphical, and mathematical communication. Like engineers in industry, students in EDC talk, write, and sketch to share ideas, and they use new communication technologies and tools, such as Visio and SolidWorks, as part of the communication enterprise. This approach to communication is vastly different from students' experience in stand-alone writing courses or the writing intensive courses that came out of WAC. It is a new, truly integrated paradigm for communication instruction.

The success of integrated approaches to communication pedagogy

While we have not methodically studied the long-term effects of EDC–because freshmen from the first full-scale class are just taking their capstone design courses in 2000-2001–we do have a growing body of information to support our positive assessment of this integrated approach to teaching communication. According to engineering faculty at Northwestern, many EDC freshmen produce higher quality reports and presentations than do some of the design teams in the senior courses. Moreover, the senior design professors say they can see their seniors approach teamwork in a more methodical and positive way than in the past[10.] Engineering school advisors report positive feedback[11.] And EDC students themselves demonstrate an enhanced appreciation of the role of communication in design. For example, in a survey that students completed at the end of EDC in 1999, one survey section asked how much students had learned in different aspects of the course (see Table 1). Answers ranged from 1 (“learned little") to 5 ("learned a tremendous amount"), using N for "no opinion" or "no opportunity to tell." We were pleased to see that while most students said they learned a lot about writing reports (77%) and making presentations (71%), an even higher percentage said that they learned a tremendous amount about the role of communication in design (85%). This may mean that even when students have doubts about their own performance in writing and speaking, they still see the connections between these inter-related fields.

Our experience suggests that EDC is successful in part because design and communication have so much in common. Both are iterative, multi-stage processes. Both require creative problem-solving. Both lend themselves to being taught with a coaching pedagogy, where instructors assume the role of guide or supervisor rather than omniscient dispenser of information. In addition, design and communication are reciprocal activities: just as reports and presentations must be well designed to achieve their goals, so must designs be communicated clearly to be understood. Even more importantly, EDC students soon learn that effective communication sharpens their thinking—and can uncover flaws in their designs. For example, as students systematically describe how various design alternatives meet user needs, they may come to recognize that certain needs are being overlooked.

However, this reciprocity is not the only reason for the success of EDC's integrated approach to communication. EDC is also successful because it provides "conditionalized learning," an approach currently being studied and verified both by scholars in communication and the learning sciences. Two such scholars are Mark Turner, a linguist and cognitive scientist who specializes in higher order reasoning and particularly the cognitive operation of "conceptual integration[12] and his colleague Francis-Noel Thomas, who works in English composition, and art history. Turner and Thomas argue in *Clear and Simple as the Truth* that writing skills are most successfully taught when they are integrated with genuine (rather than contrived) activities that build on past learning, create a real need for the new skills, and offer an opportunity to learn those skills[1]. As they explain: "Intellectual activities lead to skills, but skills do not generate intellectual activities" (p.4). In fact, they argue, "writing" as a concept cannot be taught because it is too broad, "too large to be encompassed" (p. 12). But while students cannot be taught "writing" in general, they can be taught to manage particular writing styles, which are defined by conceptual assumptions about truth, presentation, and audience. Writers can master a style as they master a context or series of relationships: What can be known? Who is trying to say what to whom? How and why? In this approach, people learn style within a specific context as a byproduct of decision-making, not as a catalogue of surface features.

If Turner and Thomas are correct, then the more that students understand the basic concepts of a field, the better they should be at mastering the communication styles associated with it and retaining the writing skills required by that discipline. In engineering design, this would mean the ability to formulate a problem statement, synthesize research, write interview scripts and surveys, outline customer requirements and design specifications, describe a design (using words, sketches, numbers), and frame an argument. According to theories of conditionalized learning, students will learn engineering writing most successfully when it is taught not as an add-on to engineering content but as an integral part of the engineering process in which engineers communicate to specific audiences for specific purposes.

Context and authenticity are also key components of successful learning according to John Bransford, Ann Brown, and Rodney Cocking in *How People Learn: Brain, Mind, Experience, and School*[134] Their two-year study of successful pedagogy, sponsored by the National Academy of Sciences, involved16 prominent educators and researchers who evaluated new developments in the science of learning. Many of these developments explain why integrated approaches to communication pedagogy are more likely to produce better communicators, with longer lasting and more transferable skills, than do more traditional modes of instruction. For example, Bransford, Brown, and Cocking applaud curriculum design that helps students organize knowledge into meaningful patterns, especially as responses to challenges. Challenge-based learning reflects the research in memory and the structure of knowledge showing that learners learn more effectively when they can plug new knowledge into coherent existing structures. Moreover, research on expertise shows that experts work from meaningful patterns of information and organize information around core concepts or “big ideas” that guide their thinking. This body of research from the learning sciences predicts the success of an innovative, learner- and project-centered course like EDC, in which “design process” functions as a core organizing concept, as do smaller themes, such as “user-centered design” and “user feedback.” Since writing skills are linked to these core concepts, it follows that they should be more durable, useful, and retrievable than writing skills taught in isolation. EDC is also structured to promote the transfer of learning by requiring students to cycle through the design process several times and apply concepts to two substantially different design projects.

III. Adapting the new paradigm to upper-level courses and modular instruction

The challenge of using an integrated approach in upper-level instruction

Engineering Design and Communication is an ideal context for teaching communication along with design, but it is not a model that can simply be replicated in upper level classes. Most engineering courses are neither interdisciplinary nor project-based; nor can each course have its own set of communication faculty as team-teachers. There is too much engineering content to cover in most courses to justify the expense of additional communication faculty; the cost of educating engineers would become prohibitive. Moreover, there is a growing trend to develop effective curricula that can be delivered electronically, over the Internet, often with no instructor present. In this context, the concept of "integrating" communication and engineering instruction needs to be re-examined. How can integrated communication instruction be accomplished in an effective and cost-effective way throughout the curriculum, as we move into the 21^{st} century?

This is the challenge faced by researchers in the VaNTH ERC who are working on an ambitious project to define and explore bioengineering education for the 21^{st} century. The VaNTH effort—comprising five research universities and experts from many bioengineering domains as well as fields such as education, psychology, learning science, and communication—involves such tasks as:

- making a taxonomy of bioengineering knowledge that will identify the relationships among the sciences, engineering, and bioengineering
- developing structures and methods for integrating knowledge and techniques from the learning sciences, learning technology, and bioengineering
- devising ways to educate future faculty members in this rapidly changing field
- developing and testing innovative assessment techniques
- providing new modular instructional materials that can be broadly and inexpensively disseminated in the academy, the school, and industry[14]

A number of VaNTH researchers are currently developing modular instructional materials, initially focusing on four bioengineering domains: systems physiology, bio-optics, biotechnology, and biomechanics. Work in each domain reflects current and new research in the learning sciences, learning technologies, and assessment.

Communication is a part of this work. Leaders of the VaNTH effort agree that communication is a key competency for engineers and an important skill for the ERC to build into its instructional schemes. In fact, the VaNTH effort assumes that the new bioengineering curriculum and resources must reflect the various competencies that have been identified in EC2000. Robert Linsenmeier, chair of biomedical engineering at Northwestern and site leader of Northwestern's ERC, uses a graphic representation (Figure 1) to show that communication is a "core competency domain." In other words, communication--like other core competencies such as design and ethics-- plays an important role in all bioengineering content domains, four of which are shown in the diagram.

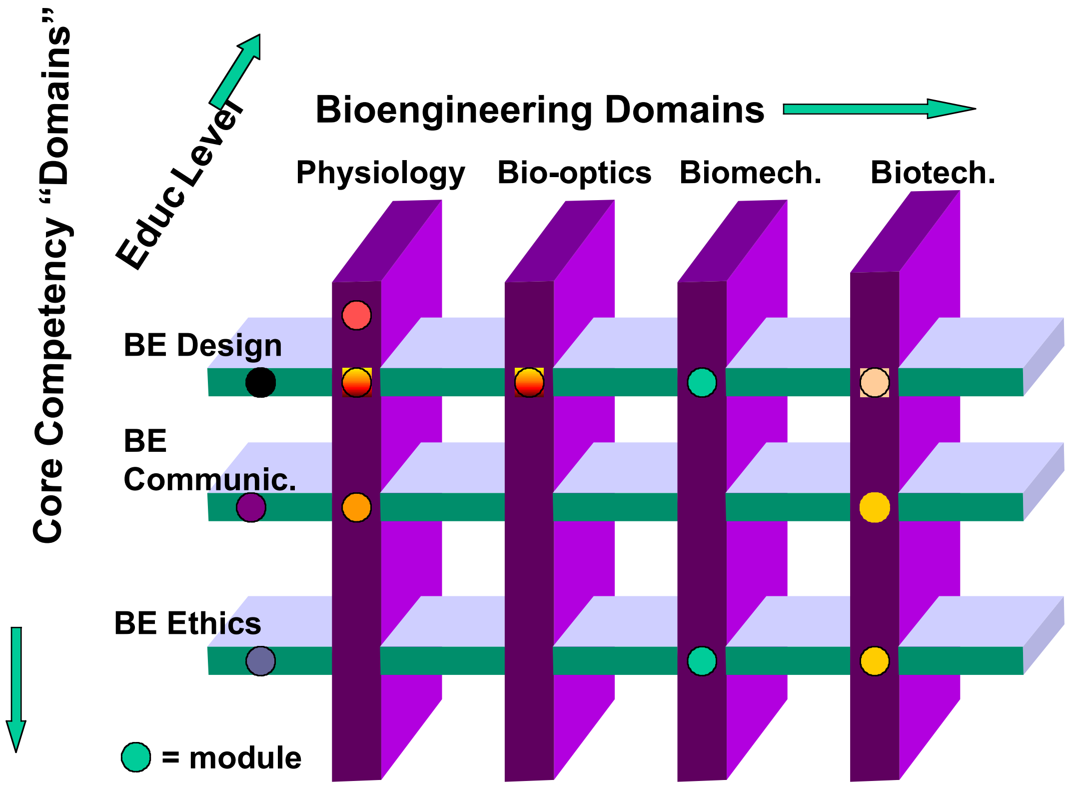

Figure 1: Relationship of Core Competency and Bioengineering Content Domains[15].

As this figure illustrates, **e**ngineering can be viewed as a set of competencies applied across content areas. The view taken by the VaNTH ERC is that in the optimal educational environment, educational modules or courses should explicitly address both content and competencies, as shown by modules at the intersections. As Linsenmeier explains, each of the domains along both axes represents a rich set of topics that the VaNTH project is attempting to define. The diagram shows only some of these competencies and bioengineering content domains.

As this framework is implemented, the goal is to build communication competence in stages, throughout the undergraduate curriculum—and to have faculty members explore curricular and extracurricular opportunities for teaching communication skills and promoting communication learning outcomes. As instructional modules are developed, the plan is for each to target specific communication competencies. Communication is also essential to the ERC's assessment efforts. David Cordray of Vanderbilt University, the "thrust leader" of Assessment and Evaluation, explains that if students can't communicate well, we won't be able to assess the extent to which they have mastered the material in any given module[16].

However, this goal of integrating communication throughout the modules is more easily said than done. The VaNTH ERC faces a mammoth task with limited funding and personnel. While communication competency is acknowledged to be important, the ERC includes few communication faculty, and promoting communication competency is not one of its major thrusts. Therefore, module writers face a challenge in seeing how they can mesh effective communication instruction with their larger goals while ensuring that their pedagogical efforts in communication are grounded in the most current learning theory—combined, for example, with authentic, intellectual, learner-centered exercises.

Pioneer efforts in two kinds of modules

At Northwestern, where an integrated freshman engineering communication program has already met with success, the VaNTH module writers are embracing the challenge of integrated communication instruction. Working with communication faculty, they have identified two different models for integrating communication instruction into new modules and are in the process of developing appropriate communication experiences and resources for students. In the first model, students are assigned specific communication deliverables, such as a paper or presentation. In the second model, students are not assigned a specific communication deliverable but module outcomes require certain communication competencies, such as the ability to support a decision with clear argumentation and adequate evidence or the ability to present results orally to the larger group in a polished, efficient manner. As a result, even these modules present many opportunities for teaching communication skills in an integrated manner. Taken together, the modules will present a larger picture to students of communication as an integral part of an engineer's work.

Below is a discussion of two modules being developed at Northwestern: one that includes specific, well recognizable communication deliverables and one that does not appear to be communication intensive but that nonetheless contains important communication components.

- *Module Type I, including a communication deliverable*

  The module on Systems Physiology (J. Troy) illustrates the first type. This module is incorporated into a course with the following three goals:

  1. To provide students with a basic understanding of the structure and function of the human nervous system from an engineering perspective. Instruction emphasizes the

structure and electrical properties of the neuron, its means of signaling, how neurons pass signals from one to another, and how collections of neurons generate system properties.

2. To provide the fundamental framework upon which a deeper understanding of neuroscience can be attained; this includes an introduction to the general terminology and basic concepts of neuroscience, as well as the tools needed to expand understanding through self-learning.
3. To stimulate interest in neuroscience, especially with regard to its quantitative and engineering aspects.

Coursework includes two group reports based on research: one on how information is coded in the nervous system and a second on how neural function can be restored, either by synthetic (e.g. neural prostheses) or biological (e.g. nerve regeneration) means. These papers are designed to give students a follow-up experience to the writing they did in freshman year and to teach specific communication competencies, namely, how to research the literature in neuroscience, go beyond the distilled version of truth presented in their textbooks, and work with others to synthesize ideas and develop an argument. The assignments are also designed to show that writing multi-authored papers is an authentic activity that researchers in BME do on a regular basis. Group writing is a particular struggle for students because it is a skill that runs counter to most of their experience in education, which tests individual performance. Writing assignments like the ones offered in this module, developed with the help of communication experts, have the potential of reversing that trend and helping students develop their competencies in collaborative research and writing.

The initial communication work in this module focused on clarifying the communication objectives and desired learning outcomes, clarifying the instructions and guidelines for the assignments, and collecting demographic information from the students, along with their work. Our next step is to analyze the groups' reports and explore additional ways to promote effective collaboration and good writing in the students' report-s.

- *Module Type II, with no explicitly labeled communication deliverable*
  A second module, in bio-optics, includes no explicitly labeled communication deliverable, like a final report, but nonetheless requires communication activities at certain points and thus presents rich opportunities for communication instruction. "Light Propagation through Tissues" (J. Walsh, assisted by Ann McKenna), is designed to help students understand the various models that describe the propagation of light in tissue. This module reveals a

common theme in science and engineering: namely, that a single physical system can be described by many different models. In this case, the students are forced to confront the advantages and limitations of various models in the context of a bio-optics problem. The students learn that simple, closed-form models can yield adequate results in some situations, yet complex, computational models are necessary in other situations. The students are presented with a real-world challenge (in the design parlance, a primitive problem): the quantification of spatial variations in oxygen concentration within the brain of a stroke patient. Real-world constraints are put on the problem (e.g. the method of quantification must be real-time, noninvasive, and inexpensive).

In small groups the students must discuss and outline potential solutions, which are presented to the entire class. Laboratory exercises are then conducted and again reported out. The exercises lead the students through various possible solutions to the primitive problem. At the end of the exercises, the students will have been exposed to the content (the models) and experimental issues (e.g. techniques and equipment), and they will have had to communicate orally and in writing among themselves and with the engineering instructor.

Even though this module is not "about" communication, by the end students have worked on interpersonal communication with their teammates, oral presentations, and written argumentation. Initial communication work in the module involved designing the assignments, building in opportunities for oral presentations, videotaping a number of the oral presentations, and giving students opportunities to reflect on these activities. The next steps are to document the module, analyze the videotapes to benchmark the oral presentation skills, analyze the arguments students made in selecting their models, and set goals for improving the communication outcomes in future iterations of the module. Another planned activity will be to develop a list of general communication goals that other module writers will be able to use. Goals from this module are being compared to those that will be implemented shortly in a new module on bio-films[17].

The VaNTH modules present opportunities to help students (1) transfer communication skills they have learned in other courses to their work in bioengineering and (2) develop specific skills in technical communication that they may not have learned elsewhere. For example, students may have learned earlier in their educational careers how to write with precision and brevity or how to support an assertion with evidence. But they may need help in learning how to be precise and concise in *bioengineering*—where is it best to use numbers, graphs, and charts instead of text? And they may need to see models of persuasive arguments. What constitutes evidence in bioengineering? What is the best way to reason? How can you verbally separate results from speculation? To promote other communication competencies, future modules might ask students to write instructions so that an experiment can be replicated; create a graph that makes text or data easy to read; distinguish among data, findings, conclusions, and recommendations; or define a technical solution for a non-technical audience. By working on these communication competencies in the context of learning discipline-based content, students should come to see that the clarity of their arguments and explanations relies equally on communication skill and a mastery of key subject matter.

Can this modular approach to communication instruction provide a genuine, integrated approach?

Teaching engineers how to communicate effectively is not something that can be done in one module, or even two or three. However, to achieve this goal, it is not necessary for every module to include a communication component. Rather, there must be a critical mass of modules that support and build on one another and that work together to help students acquire a broad and realistic understanding of communication in engineering—one that includes oral, interpersonal, and graphical communication as well as written communication. If enough VaNTH modules provide communication instruction, require communication competency, and articulate a complex understanding of what it means to communicate effectively in bioengineering, then students who complete the bioengineering sequence will get the message that communication in engineering is indeed multifacted and integral to the engineering enterprise.

Making this happen necessitates that the engineering faculty work together as a team with a common mission—to help students develop as better communicators. It also necessitates that they develop a shared understanding of communication as a complex, multifaceted enterprise—and thus coordinate their instruction so that students learn a wide range of communication competencies by the time they graduate. And, finally, it necessitates that the engineering faculty work with communication experts, as well as experts in the learning sciences, to devise innovative learner-centered communication assignments and resources. Only by working together in this way can faculty help students see that good communication is more than a matter of grammar and punctuation; it is just as much a matter of creating effective graphs, holding productive meetings, understanding the needs of a client, communicating a proposed solution to that client, and writing a logical detailed plan that can be implemented. In other words, good communication is a core competency that engineers rely on in every facet of their work. It is our hope that the VaNTH approach to integrated, modular instruction will prove to be an effective, reproducible model for achieving these goals.

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