Int. J. Engng Ed. Vol. 17, No. 1, pp. 67–74, 2001
Printed in Great Britain.

0949-149X/91 $3.00+0.00

A Model for Integrating Skills across the Biological Engineering Curriculum*

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This paper details a model for integrating communication skills (oral, written, group/team, and leadership) across an undergraduate biological engineering curriculum. Instruction in these areas is provided within some of the core courses and has been key for student success. Communication skills are expanded upon as students progress through the curriculum and culminate with the senior capstone design sequence. In this paper, we present this model and discuss the positive ramifications it has had on student learning. Problems encountered include student and faculty resistance and lack of resources. Recommendations for implementing such a model in any engineering curriculum are detailed.

INTRODUCTION

ENGINEERING is widely viewed as a discipline in which mastery of technical skills (mathematics, engineering and basic sciences, and engineering design) are critical to success. However, a long-standing perpetual complaint from employers hiring entry-level engineering graduates is a lack of communication skills. This concern is illustrated with the following quote [1]:

> Staying up-to-date with technical advances in your field is imperative to your success. But in order to succeed today, you also need to be armed with tools that extend beyond traditional engineering. These tools include knowledge and practical application of communication skills – to know yourself and to work effectively with your manager, co-workers and customers . . . These tools are not necessarily taught in engineering school, but they are essential for engineers to survive and succeed.

Engineering faculty are committed to the future professional success of graduates, but curriculum design efforts have centered largely on technical mastery. The biological engineering curriculum at LSU was re-designed to incorporate communication and teaming skills across the curriculum.

Substantial literature exists regarding the pedagogy and practice of Writing Across the Curriculum (WAC) initiatives for all disciplines [2–4]. WAC is an educational reform effort to improve students' writing ability and learning experience using the following principles [5]:

1. Writing skills must be taught and practiced throughout the curriculum.
2. Writing results in enhanced learning.
3. Writing is fundamentally important in a college education.

Numerous engineering programs across the country have adopted WAC initiatives, and several have reported on these efforts [6–8]. Manuel-Dupont [6] describes a WAC program developed for the department of Civil and Environmental Engineering at Utah State University and critiques efforts in this area. The author states that the major impediments to implementing a successful program include getting faculty from technical fields to participate as WAC instructors, lack of administrative support and resources, and lack of knowledge concerning the actual writing experiences that are needed for 'real world' situations.

WAC is an important and successful reform movement [3–4, 9–10]. However, we believe that writing is only one of several critical communication skills that our graduates must possess. Thus, we designed our curriculum using the principles of WAC, but we included teaming and leadership skills in addition to oral and written communication skills. There is limited literature regarding these other skills in engineering curricula [11].

This paper represents a concerted effort to integrate communication skills across a biological engineering curriculum. Our objectives are (1) to describe our approach, (2) to discuss the impact on student learning, and (3) to detail recommendations for implementing this kind of program.

METHODOLOGY

Communication skills were implemented across the biological engineering curriculum with the

* Accepted 15 April 2000.

Table 1. Curriculum configuration for instruction regarding communication skills

Year	Course	Credit hours	Skills to be mastered: group, leadership	oral	written
1	BE 1250: Introduction to Engineering Methods	2	x	x	x
	BE 1252: Biology in Engineering	2	x	x	x
2	BE 2352: Quantitative Biology in Engineering	3		x	x
2/3	ENGL 3002: Technical Writing	3			x
3	BE 3340: Process Design in Biological Engineering	3	x	x	x
	BE 4303: Engineering Properties of Biological Materials	3	x	x	x
4	BE 4290; Senior Engineering Design and Professionalism	2	x	x	x
	BE 4292: Senior Engineering Design Laboratory	2	x	x	x
	BE 4341: Biological Reactor Design Systems	3		x	x

principle that they must be taught and practiced throughout the curriculum. Most instruction regarding communication skills takes place within the first two years of the curriculum, and most building and 'fine tuning' exercises occur during the second half of the curriculum. Learning objectives in course syllabi include mastery of written, oral, group, and leadership skills. Assessment of these skills occurs through assignments (both formal and informal), exams, instructor observation and critique, and student reflection and assessment of themselves and others. Although up to the individual instructor, mastery of communication skills was a significant component of the grade for each course. Individual skills are targeted in each course according to the scheme shown in Table 1. All courses are required to complete the curriculum. Specifics regarding each course are detailed in the paragraphs below.

BE 1250 and 1252

These courses provide an introduction to biological engineering, including detailed study of the discipline and the engineering design method as it applies to biological engineering. These tasks are accomplished using a hands-on, inquiry-based approach in which students must solve real-world problems in assigned teams of two to four students; written, oral, group, and leadership skills are key components of this process. A resubmission process for written assignments in BE 1252 allows students to improve their skills in a stepwise fashion, with the final goal of quality work. A summary of assignments and instructional units specifically geared toward development of communication skills is included in Table 2. A variety of instruments are used to assess oral, written, group, and leadership skills. Readers are encouraged to consult References 12 and 13 for more detailed information regarding pedagogy and assignments to develop communication skills and to assess these skills.

A student portfolio [14] is initiated, in which students are required to compile assignments (technical and communication skill oriented) through a process of selection, evaluation, and reflection. The portfolio is intended to span the students' college careers. Each student's team and leadership skills are evaluated through self-assessment, confidential assessment by each of their team members, and assessment by the instructor. This assessment is worth 50% of each student's group grade, while technical merit comprised the remainder of the grade. Tests, in and out of class assignments, and the student portfolio were used to complete the assessment process. Communication skills account for about 50% of a student's grade in each course.

BE 2352 and ENGL 3002

BE 2352 involves the characterization of biological phenomena in engineering design, statistics, and case studies of engineering design solutions.

Table 2. Communication skills and assignments to reinforce these skills for first-year courses

Instructional units	Assignments
presentation of data/objects (computer aided design, graphs and spreadsheet programs)	drawings (2 and 3D); graphs, programs turned in as homework sets, design projects
incidental and in-class writing	journal, written samples assessed by teacher
proposal, resume and business letter writing	written assignments are graded and sent to actual clients
oral presentation	assessment instrument designed by students and professor together; filled out by self, students, teacher, and experts
conflict resolution working in teams	in class team-building exercises, test/homework sets regarding skills taught in class, students reflect on experiences through journal
leading a team	rotate team leader for meetings; self-assessment, instructor and group member assessment, quality of team project

Students expand upon the communication fundamentals they learned in BE 1250 and 1252. Numerous writing assignments are required for the course, including reflective essays (autobiographical sketch, self-assessment narrative, learning philosophy, mission statement) and laboratory reports. Students are also required to teach a fifteen-minute unit to their peers on an aspect of biological engineering in which they are interested. They also have the option of teaching a science or math topic to local elementary schoolchildren. Instruction on writing laboratory reports and effective oral communication in a teaching capacity is provided in the classroom. The instructor and students create an assessment instrument for the oral presentation, and all students, the instructor, and the speaker assess their performance using this instrument. These exercises are included as part of the student's portfolio and are worth 35% of the student's grade. Students also have the option of resubmitting assignments in which their grades are less than 80%; if they choose to do so, they must re-do the problems and provide a detailed, written explanation of what they didn't understand and how they resolved it. The student's final grade is an average of the two assignments; this exercise is intended to improve the student's writing skills and to help the student clarify their understanding.

ENGL 3002 is a required technical writing course taught in the LSU Department of English. Writing skills and assignments are worth 100% of the course grade, and assignments include a resume, technical paper content and form, proposals, a prospectus, executive memos, and cover letters. This course is required for all engineering majors, so the writing skills taught address the engineering discipline as a whole. This fundamental approach complements the discipline-specific writing assignments required in core courses of the curriculum.

BE 3340 and BE 4303

BE 3340 addresses the development of processing flow charts, process economics, and design of biological processing unit operations. The objectives of BE 4303 include the study of physical, biological, chemical, and engineering properties of biological materials and application and response of these materials in biological systems and engineering design.

Communication aspects of both courses are emphasized through project proposals and progress reports, laboratory reports, essay questions on exams, and oral presentations. Daily reflective journals and course evaluations are also required and reviewed three times a semester. A final laboratory assignment for each course requires students to form teams of their own choosing, to formulate a problem, to design appropriate experiments that give hands-on experience with property measurement equipment, and to complete written and oral reports of their results. Team members must write individual reports to allow a better assessment of their writing performance. Students can resubmit work from tests, homework, and written reports; this process provides a self-disciplinary approach for grade improvement while allowing the students to learn from their mistakes. Assessment of the writing on all reports constitutes approximately 20% of the report grades, which account for 25% of the total grade for the class. Oral presentations constitute an additional 10% of the final report grade.

BE 4341

The goal of this course is to extend the fundamental principles governing microbial growth and biochemical reactions to the design of biological reactor systems used for waste treatment, cell production, and product formation. Assignments for this course cover written, oral, and team communication skills.

With respect to writing skills, students are required to prepare laboratory reports for each major lab exercise and a written report of their independent final project. In addition, students must keep a journal for the course, in which they are encouraged to reflect on the material presented in lecture and lab, to summarize major points in their own words, and to pose questions or identify areas that need further clarification.

Oral communication skills are enhanced in the preparation and delivery of a fifteen-minute presentation of the results from their final project, in conjunction with their choice of graphics presentation (typically overhead transparencies or a PowerPoint presentation).

Teaming and individual-competence skills are used through the laboratory exercises and final project. The lab facilities are designed to accommodate teams of two to three students. Laboratory exercises are partially open-ended; in each lab exercise there are choices that the students within each team need to make, such as the proper dilutions to prepare, the number of samples to collect, or the suitable analytical methods to use. In addition, most laboratory exercises continue throughout the course of the week, so that students within each team must coordinate their sampling schedules and protocols. In contrast, the final project is an independent activity, intended to ensure that each student is competent in the basic skills of designing, operating, collecting data, and analyzing results from a biological reactor. Communication skills are worth 15% of the course grade.

BE 4290 and BE 4292

The objectives of this senior capstone design sequence are to enable the students to develop a team design project and to become familiar with the process and philosophy of design, ethics, and professionalism. During the fall semester, students choose teams of two to four people and initiate a design project of the group's choosing. All students keep an individual design notebook and are instructed on how to do so. Instruction regarding proposal and project reports in the context of engineering design is also included.

In BE 4290, student teams write and orally present a design proposal and a project report during the semester. At the end of this course, the teams are expected to complete the first iteration of their design. They write a progress report and present their design to all professors, students, and interested members of the community in a combined poster/presentation session. In BE 4292, the teams complete their designs, build a prototype, and test the prototype. The students write and orally present two progress reports during the semester. BE 4292 culminates with a final written and oral report using the same format as in BE 4290. All the work, including reports and presentations, is accomplished as a team. This design sequence builds on the team dynamics learned in previous courses. The purpose of this exercise is to train students to successfully work on an engineering problem as part of a team in a real-world, industrial setting.

RESULTS AND DISCUSSION

Students are better prepared for their careers when communication skills are implemented across the curriculum. We base this assertion on instructor observation and reflection, the quality of assignments, exit interviews of students, mean grade point average of ENGL 3002 before and after the communication-intensive curriculum was put into place, and the success of the students in situations that require strong communication skills.

Instructor observations and reflections

Many students resisted the communication-intensive curriculum initially. This could be due to a number of factors; for example, some students who started the non-intensive curriculum were not used to working actively on communication skills. The attitude of the instructor was also a factor; one instructor noted that student resistance diminished when students were told firmly that 'this is the way it is' and were told the benefits (practical applications) of their work in this area. Instructors have noted that student resistance has decreased over time and is now minimal throughout the curriculum.

All instructors have observed that students embrace the study and practice of communication skills to varying degrees. Although all students complete these requirements, some participate because they have to, while others incorporate strong effort because they believe it will aid their learning and help their careers. This concept is illustrated by students taking BE 4341; the instructor has observed that students fall into four groups with regard to the keeping of a journal for the course:

1. Students who do not take full advantage of the instrument. These students write a few sentences of minimal usefulness, referring in broad terms to what was covered that day, or fail to keep a journal at all. This group constitutes approximately 50% of the students.
2. Students who write detailed summaries of each lecture and lab. This appears valuable to students for reviewing materials for exams and aids in their understanding of material. However, these students do not tend to analyze the material. This group constitutes approximately 25% of the students.
3. Students who organize their entries into succinct outlines that summarize major points of each class. This is very helpful for pulling together all the information into a cohesive set, and seems very useful to the student. These students benefit from the journal exercise because the process of organizing and condensing the material allows them to analyze relationships among components of the material. This group constitutes approximately 12.5% of the students.
4. Students who ruminate on the page about each class. They summarize information but also question why a phenomenon occurs, relate the information to other classes, and present opposing information obtained from other sources. Although this style may not aid in reviewing material for exams as much as the outline format, these students benefit from the time spent thinking about the material and questioning its implications. This group contains the remaining 12.5% of the students.

It is interesting to note that these observations correlate with Bloom's taxonomy [15] and the Newcomb-Trefz model of the learning process [16]. The first group of students, who do not benefit from the journal, are exhibiting the *information stage* of learning, in which students can define, repeat, list, name, label, memorize, recall, and/or relate to the information presented. This is regarded as the lowest level of learning. The second group of students demonstrates the *knowledge stage* of learning, where students can explain, compare/contrast, identify, discuss, and summarize concepts. The last two groups of students demonstrate the third level of learning, *application and analysis*, in which students can solve problems by applying information gleaned from the knowledge stage of learning and can critically distinguish the logical components of applications of that knowledge. Some students appear to reach the highest level of learning, *wisdom*, in which the student displays professional judgment and the ability to synthesize, organize, plan, manage, teach, and/or evaluate material from the first three levels of learning. These results suggest that the journal can facilitate learning at higher levels of cognition (application, analysis, and wisdom vs. information and knowledge). This process is partially dependent on the buy-in and effort of students, however.

All instructors who employed the journal in class noted that a number of their students mentioned when there was information they didn't understand or material that was presented too quickly. Thus, the journal was extremely useful to the instructor to assess student comprehension and teaching methodology, and to receive constructive criticism for improving the course. One instructor noted that the information relayed in the journals was more useful for course feedback than standard student evaluation.

Implementing this curriculum has caused better communication among professors regarding weaknesses of the students and where these weaknesses should be addressed in the curriculum. In one example, students had difficulty with the graphical representation of data in BE 4341; this information was relayed to the instructor of BE 2352. In subsequent years, students learned graphical representation in BE 2352 and were already proficient when they reached BE 4341. This type of communication is important for the quality of the curriculum and for accreditation (continuous quality improvement of curricula is one requirement of newly enacted Engineering Criteria 2000, by the Accreditation Board of Engineering and Technology). This process also occurs between the faculty and the department head (see section entitled 'Exit interviews of students' below).

Quality of assignments

Instructors of the senior level courses have observed an increased proficiency in students' writing, speaking, and teamwork ability, and an increase in the quality of assignments from a communication and technical standpoint. These include an improvement of complete laboratory reports, to the point that the undergraduate students in our curriculum consistently outperform students from other engineering disciplines taking biological engineering courses and graduate students who did not complete their BS degrees in our curriculum. Senior design projects and corresponding documentation have also steadily improved.

A notable quality of biological engineering seniors is a lack of discomfort or nervousness in presenting their work in front of the class. We believe this is due to the prior experience the students gained from freshman through junior communication-intensive courses, though some problems with presentation fundamentals still exist. Further instruction on the required elements of an oral presentation will be added to the freshman and sophomore courses to address this concern. Most seniors work together very well and appear to execute rudimentary techniques for teamwork, leading teams, and conflict resolution. Though miscommunications among team members still occur, the students have a framework for dealing with these problems and thus gain experience dealing with teamwork obstacles.

Exit interviews with students

The department head conducts exit interviews with graduating seniors during the last few weeks of each semester. Each course in the curriculum, especially those in the department, is examined. The students' perspectives on course content, relevance of materials, success in meeting course objectives, quality of instruction, and related issues are discussed. The relative importance and value of each core course is closely examined. This information is shared with faculty at the annual retreat, and changes are recommended for continuous improvement of courses and curriculum. Faculty interaction and sharing of this information have resulted in better technical subject matter coordination and incorporation of procedures to improve on team-building, interaction, communication, and student learning, especially in the pre-professional experience of senior capstone engineering design sequence.

The recent emphasis and option of an international senior design experience will further enhance this learning process to prepare our students for the real world with better communication and teaming skills.

Mean grade point average (GPA) of students taking technical writing

One quantitative assessment measure is the comparison of the mean GPA of students taking technical writing before and after the curriculum was implemented. Before the communication-intensive curriculum was adopted, the technical writing course constituted the bulk of writing instruction that the student received. After implementation, the student has already engaged in at least two communication-intensive courses in the curriculum before taking technical writing. Thus, we anticipated that these students would be better prepared than those who had no prior training.

Table 3 shows the mean GPA obtained by biological engineering students in technical writing before and after the communication-intensive curriculum was instituted. Students had a statistically significantly higher GPA in technical writing after the communication-intensive curriculum was adopted (pooled t-test, $P \leq 0.05$). Although we cannot prove that the increase in GPA is due solely to the implementation of the communication-intensive curriculum, this trend is encouraging.

Student success

Our students have had unprecedented success in the past several years in activities that require strong communication and teaming skills, including the following:

- In 1998, a team of BE students placed third out of fifteen in a regional debate on ethics and professionalism in engineering.

Table 3. Mean grade point average of students' grades in technical writing before and after the communication-intensive curriculum was implemented

	Before curriculum change (1992–1995)	After curriculum change (1997–1999)
Mean GPA	3.118	3.574
Standard deviation	0.60	0.50
Number of students	17	47

Note: 1996 students were not included because they were in the transition year between curriculum changes.

- Since 1997, nine senior design teams have secured funding (via formal proposal writing) from the LSU College of Agriculture, the LSU Department of Civil & Environmental Engineering, and local engineering firms to design and build their projects.
- Two senior design teams placed first and fourth in 1999 national design competitions sponsored by the Institute of Biological Engineering and the Society for Engineering in Agricultural, Food, and Biological Systems, respectively.

These successes are directly linked to the students' abilities to communicate in written and oral format and to work together in teams. We believe that much of this success can be attributed to the implementation of our communication-intensive curriculum.

CONCLUSIONS AND RECOMMENDATIONS

Students are better prepared for their careers when communication skills are implemented across the curriculum based on quantitative and qualitative assessment measures. We offer the following recommendations for implementing communication-intensive curricula in any engineering discipline.

Be prepared for initial student and faculty resistance

Students will resist what they consider to be extra, superfluous work. If instructors stress the importance of communication skills to the students' future professional success and connect the development of these skills with technical knowledge, resistance will be minimal. Faculty resistance can arise if instructors feel like they should add communication material into limited class time and if instructors believe they lack expertise regarding communication skills.

Faculty resistance can be minimized by stressing that a small amount of class time spent on communication skills instruction has a big impact. Also, not every course needs to contain instruction on communication skills, only opportunities to practice them. Students can also educate themselves through out-of-class venues such as computer tutorials, visits to the university writing center, and participation in extracurricular activities that stress public speaking, working in groups, and conflict resolution. These activities can be required for a course or encouraged by a faculty member.

Faculty members are experts in communication skills in a discipline-specific fashion and sometimes need to be reminded of this fact. Some faculty had questions regarding grammar and language usage. At LSU, the College of Agriculture employs a teaching assistant whose job is to assist faculty in this regard; our faculty have made use of this highly recommended resource. University communication experts can be invited for guest lectures for students *and* faculty. In addition, the university faculty development office can also assist faculty in developing and executing communication-intensive courses.

Get resources or make use of existing ones

Faculty and staff time are a concern because grading takes longer with communication-intensive skills added into the curriculum. Paid staff and faculty release time can help immensely with this process, as well as administrative support in terms of experts to assist students and faculty with communication skills. Partnerships between university WAC and/or communication programs can also be helpful. Faculty release time should be granted for those who lead this process, which should include a model curriculum, specific communication skill objectives for each course, and an assessment strategy for determining if the objectives have been met.

Plan and execute an assessment strategy

This process is imperative and should begin at the same time that the planning to implement a communication-intensive curriculum begins. Readers are encouraged to consult publications such as The Journal of Engineering Education, The *International Journal for Engineering Education,* and Prism magazine for information on planning and executing an assessment strategy.

Acknowledgments—The authors acknowledge current and former faculty members in the Department of Biological and Agricultural Engineering at LSU, including Bob Edling, Tom Lawson, Mike Mailander, G. Scott Osborn, Fred Sistler, and John Henry Wells for their efforts in implementing communication skills into the curriculum. Jane Honeycutt of the LSU Agricultural Center proofread the manuscript. The LSU College of Agriculture provided part-time teaching assistants for the Writing Across the Curriculum (WAC) project, who have helped our faculty implement WAC and our students with their writing skills. The LSU Division of Instructional Support and Development and Malcolm Richardson have assisted our faculty with communication and WAC issues.

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