# Team-Based Written Communication Exercises for Biomedical Engineering Juniors: Where To Do It and What Works

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*Abstract:* ABET EC2000 challenged engineering educators to structure learning so that (1) competency is built progressively throughout a curriculum and (2) the notion of "competency" includes not only bioengineering knowledge, but other important professional skills, such as teamwork and communication. Meeting this challenge is difficult in an over-crowded biomedical engineering curriculum, where mastery of domain content is generally emphasized. Nonetheless, at Northwestern University, with support from the Vanderbilt-Northwestern-Texas-Harvard/MIT (VaNTH) Engineering Research Center, we have piloted a way to integrate team-based writing instruction into a junior course on neural systems physiology, targeting specific aspects of writing with which juniors seem to have difficulty. This article describes how writing was added to the course without diminishing the emphasis on content, plus the theory that underlies this instructional intervention. Also discussed are the results of a formal assessment to measure student gains in collaborative writing and implications for future interventions in this and other engineering courses.

ABET EC2000 challenges engineering educators to structure learning so that competency is built progressively throughout a curriculum. The engineering community well understands the need for proficiency in all modes of communication, with written communication considered of high importance. For example, a panel of ten representatives from biomedical companies, assembled at Northwestern University in the summer of 2001, stressed the importance of communication skills for entry-level biomedical engineers. Representatives from Abbott Laboratories, Datex-Ohmeda, and Nova Bionics said that entry-level engineers in biomedical engineering specifically need to be able to detail all project subtasks in project design, find and evaluate research relevant to a project, write succinct reports for management on a project's progress, assemble proposals for internal funding of a project, generate simple, to-the-point presentations, and publish the results of project research.[1] Industry practitioners similarly emphasize the need for entry level engineers to work effectively in teams. Both competencies—communication and teamwork—are specified in EC2000.

However, in a crowded biomedical engineering curriculum, where students need to master much knowledge and many skills, it requires some ingenuity to fit communication exercises seamlessly into courses, especially during the sophomore and junior years, where emphasis is often placed on gaining content knowledge. Moreover, the problem is compounded by the fact that few engineering faculty have formal training in communication pedagogy or even time to assess student performance in communication, which usually necessitates a substantial increase in workload.

At Northwestern, we have made a concerted effort to integrate writing exercises into engineering courses, ensuring that students appreciate the part played by written communication in engineering practice. For the past seven years, our freshmen have received written and oral communication instruction within the context of team-based design projects that are taught collaboratively by faculty from engineering and communication.[2] Biomedical engineering majors have also been given an opportunity to refine their writing skills in senior laboratory and design courses. For example, they receive some instruction and coaching from Writing Program faculty who work informally with the design professors. However, sophomores and juniors in biomedical engineering have for the most part lacked similar opportunities, with this gap in the curriculum being a serious detriment to their learning. First, the inattention to writing between the freshman and senior years sends a contrary message: that communication is not, indeed, essential to the engineering enterprise. Second, with a two-year gap, seniors most likely forget what they learned about writing as freshmen. Third, bioengineering students do not learn how to apply the general writing skills they acquired as freshman to their chosen technical discipline.

To address these deficiencies, we have been testing team-based writing exercises in a required junior level neural systems physiology course, with support from the Vanderbilt-Northwestern-Texas-Harvard/MIT (VaNTH) Engineering Research Center.[3] This paper reports on that effort, showing how one can indeed integrate team-based writing instruction into a bioengineering course so that it (a) supports the overall course goals and, (b) by targeting specific aspects of writing with which juniors seem to have difficulty, potentially improves students' writing proficiency. We describe the theory that underlies our instructional interventions, the interventions themselves, modifications that we have made over the years, and the assessment we are using to measure student gains in team-based writing. We hypothesize that the approach described in this paper can be successful in a number of courses, and, if widely used across a department, could vastly improve bioengineering students' communication skills and their understanding of the importance of good scientific communication to their future careers.

## Where to do it, or BMD ENG 301 and VaNTH

Biomedical Engineering 301 at Northwestern is a course in the physiology of neural systems taken each fall by 50 to 60 juniors. It has been taught for the past 14 years by the same instructor, who was, for most of that time, the director of undergraduate studies in Biomedical Engineering. Thus, the instructor was well aware of the potential value of adding writing instruction in the junior year.

Four years ago BMD ENG 301 became one of the focal points for the pedagogical innovations sponsored by the VaNTH Engineering Research Center (ERC), a National Science Foundation funded alliance of educators, engineers, and industry partners developing curricula and technologies for tomorrow's bioengineers. VaNTH is a cooperative effort among Vanderbilt University, Northwestern University, the University of Texas, and the Harvard University/MIT division of Health Sciences and Technology (i.e., VaNTH.). Faculty teams of biomedical engineers, learning scientists, and learning technologists work together and with industry representatives to create challenge-based learning modules, or segments of courses, that can be plugged into new or existing BE or BME curricula. All modules reflect the theory and research on effective teaching and learning compiled in *How People Learn* (HPL) (Bransford, Brown, and Cocking [eds.] 1999),[4] a two-year study sponsored by the National Research Council, thus ensuring that modules involve problem- or case-based challenges that are sensitive to the four key dimensions of most successful learning initiatives.

Thus, all VaNTH modules aim to be:

- *Knowledge-centered*: helping students (a) *learn with understanding* by organizing knowledge around key concepts and (b) move from novice to expert problem-solving methods
- *Learner-centered:* (a) taking into account the knowledge, skills, preconceptions, and learning styles of all students and (b) starting with what students know when they enter the class
- *Community-centered*: (a) encouraging students and faculty to learn from one another and (b) situating learning within real-world ("authentic") challenges
- *Assessment-centered*: (a) providing frequent opportunities for students to make their thinking visible, so their misunderstandings can be corrected, and (b) revising teaching and learning activities after measuring student learning

In addition, modules reflect two other key VaNTH activities: a taxonomy of core concepts and skills in biomedical engineering, which is intended to become a central document for curricular planning, and a taxonomy of related core competencies in areas such as communication, ethics, and teamwork. This latter taxonomy resembles other taxonomies of "soft skills" that are under development, such as the CDIO taxonomy in the Aeronautics and Astronautics Department at MIT,[5] or that of communication skills drafted by the Liberal Education Division of the American Society of Engineering Education.[6] Like those taxonomies, VaNTH breaks down or "unpacks" large complex areas like "writing" and "teamwork" into teachable units that focus on specific skills with potentially measurable objectives.[7] For example, in the VaNTH core competency taxonomy, "graphical communication" is broken into four sub-sections: (1) using sketches, drawings, and photos effectively, (2) constructing useful tables, graphs, and charts, (3) integrating graphics with explanatory text, and (4) interpreting and constructing technical drawings and renderings. Each of these sub-sections is, in turn, broken into separate, teachable skills. Students who are learning how to use sketches and drawings, for example, must learn how to choose the correct amount of detail to accomplish their purpose, label key parts, avoid distortion, cite sources, and acknowledge manipulation of scale. The taxonomies are useful tools for individual module developers, who can focus on lessons that teach discrete skills, as well as for developers of departmental curricula, who want to see if most key skills are being taught across a range of years and courses.

Biomedical Engineering 301 is an HPL-inspired course that has six goals:

- Provide 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, and how neurons pass signals from one to another. The organization of neural systems on a macro scale is also considered within the context of operation of the somatosensory, visual, and motor systems.

- Provide the fundamental framework upon which a deeper understanding of neuroscience can be self-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.

- Stimulate interest in neuroscience, especially with regard to its quantitative and engineering aspects.

- Improve student capability in technical written communication.

- Enhance student performance in team-based work.

- Familiarize students with primary source scientific publications.

Teaching and learning take place in three one-hour lectures and one one-hour discussion session per week and through three laboratory exercises.

**How to do it**

BMD ENG 301 supports writing instruction by asking students to write two team-based research papers that encourage them to explore the relevant literature that lies beyond the textbook. Students work in groups of four or five. As they develop their understanding of specific topics in neural systems, they also learn that many puzzles are unsolved and that scientists and engineers are engaged in active research and debate related to neural systems. The paper topics are integrally related to the biomedical engineering course content but also to the activity of professional engineers. Moreover, the papers are graded by the engineering instructor, whose comments show that writing proficiency is an important and integral part of biomedical engineering.

The writing assignments are a good example of "writing across the curriculum," the WAC movement in composition instruction that emphasizes the importance of learning how to write within specific contexts and disciplines.[8] However, the writing assignments in BMD ENG 301 are consistent with the learning theory emphasized in VaNTH, which is not necessarily the case with WAC assignments. Emphasis is placed on helping students work collaboratively within an authentic context—in one case, the way that real scientific researchers work in the field of neural coding—which is a primary VaNTH goal (and is similar to WAC). However, in addition, the assignments are designed to help students develop the critical thinking skills needed to be an "adaptive expert" in biomedical engineering, another key VaNTH objective. All VaNTH instruction, whether geared toward mastery of domain skills or related core competencies, aims at helping students understand the deeper concepts that underlie skills development, thus facilitating their ability to transfer skills and knowledge from one problem to another and to deal more comfortably with ambiguity, solve novel problems, and communicate at a high level.[9] Finally, in conjunction with the writing interventions, steps are put into place to measure student learning and revise the assignments accordingly. This is another characteristic VaNTH approach.

Embedding communication instruction into BMD ENG 301 involved an iterative process carried out over a five-year period (1999-2003):

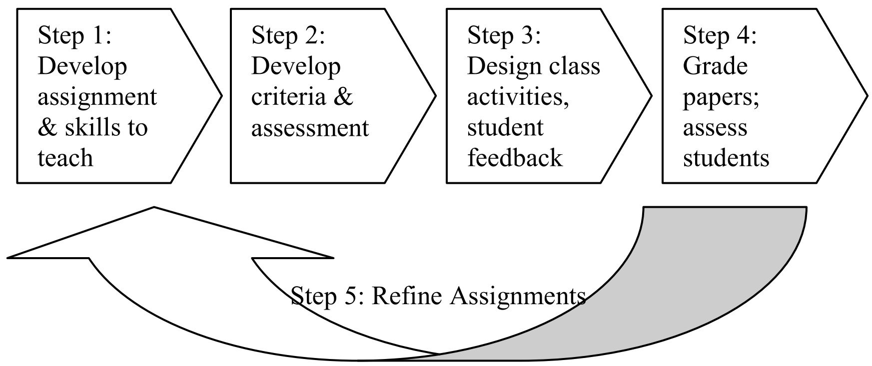



Figure 1: How to Teach Team-Based Writing in BMD ENG 301

*Step 1: Developing the assignment and specific skills to teach.* Any instructor teaching a junior-level course in a crowded curriculum is bound to ask, "Is it worthwhile for me to sacrifice class time from teaching biomedical engineering in order to help students improve their writing? Is this trade-off a good one?" Careful planning is necessary therefore to ensure that the writing assignment will indeed support key course goals and not just be a superfluous assignment that students will perceive as busy work. In BMD ENG 301, both team-based writing assignments focus on topics that students need to explore:

- How information is coded in the nervous system
- The recovery of neural function through biological or artificial means

The first assignment especially, because of its difficulty, warrants extra time and a chance for students to work collaboratively in a reflective way. Students are asked to familiarize themselves with a variety of opinions on this key issue, synthesize their learning, and then develop their own answer to the question of how information is coded by neurons. This is an area of neural systems research in which engineers, mathematicians and physicists have contributed significantly. The second assignment is in an area of neural systems research where the contribution of biomedical engineers has been substantial too. But in this case, the biomedical engineers involved have largely been those with a chemical engineering or materials science research emphasis. Hence, the two assignments provide students with exposure to the breadth of biomedical engineering research while at the same time gaining an appreciation for the common rules of writing that apply within the discipline.

In developing these assignments, one of our first tasks was to define what we meant by "helping students improve their capabilities in written technical communication." To decide which specific writing skills to target for improvement, we analyzed the instructor comments on papers from two early classes (BMD ENG 301 Fall 1999 and 2000) to see where the juniors seemed to require the most help with their writing. Looking at those comments in relation to skills listed on an early version of the VaNTH core competency taxonomy, instructors identified five specific learning objectives for writing in the course:

- Writing concisely
- Using figures, tables and equations, as well as text, to explain ideas (in other words, realizing that engineering communication is multifaceted)
- Synthesizing ideas from multiple research papers
- Using headings and so forth to add structure to reports
- Citing others' work appropriately

*Step 2: Developing criteria and related assessment.* Once learning objectives had been established, we outlined the criteria to be used in grading and developed criteria sheets that could be given to students along with the assignments. The categories were writing content, writing quality (grammar, spelling, style), organization, innovation, scholarship. With the criteria sheet in hand, students would know for example, that an "A" paper would, in terms of content:

- Have a clear point to make: describe a problem, summarize recent breakthroughs, evaluate existing techniques, advance an argument, etc
- Show an understanding of the assigned readings (that is, current research on the topic)
- Be concise, using space effectively to highlight important ideas and subordinate less important ideas
- Explain ideas clearly, using figures and tables when appropriate
- Offer evidence or reasoning to support all claims
- Have a substantial conclusion

Students would receive a grade and written comments on the first paper, which they could use to improve their writing in the second paper. Together the papers counted for 12% of the quarter grade, which was sufficient to ensure engagement among our highly motivated student population.

*Step 3: Planning class activities and resources.* Since one goal was to improve student writing by using assignments that would require a minimum amount of class time, short handouts were developed to give students advice about writing in groups. Each year at least one class session was devoted to the writing assignments, although the nature of this session varied. One year it involved a debate; another year the instructor analyzed the conventions of some of the articles assigned for the writing project. In 2003, students were also encouraged to take drafts of their second papers to the university's peer tutoring center for additional review.

*Step 4: Grading the final paper.* Instructor grading is the most time-consuming and important activity, especially on the first paper, since students presumably use that feedback to improve their writing in the second paper. To promote efficiency and fairness in grading, a grading rubric was created that mirrored the criteria from the assignment sheet. This rubric supplemented the instructor's comments.

*Step 5: Refining the assignment.* From 2000 – 2003, refinements in the assignment were based on the instructor's evaluation of student progress, in consultation with other learning experts from VaNTH. These are discussed below. In 2004, additional refinements will reflect the results from this year's more systematic assessment.

**What works and lessons learned**

*Positive anecdotal feedback and minor refinements.* Overall, this intervention—an embedded writing assignment—has been consistent enough with VaNTH theory and the instructor's assumptions about what best promotes student learning that it has been retained in the course, with slight variations, for five consecutive years. Both positive feedback from students, indicating the usefulness of the exercise, and the fact that the second papers are generally scored higher by the instructor than the first ones, suggest that some improvement in writing is taking place.

Over the five years that we have been running this exercise, we have made a number of "discoveries" that have necessitated minor revisions. For example, in 2000, we realized that students were too worried about "getting things right" to participate wholeheartedly in a debate on the highly contentious issue of what is the neural code. Their natural inclination was to cover every possible point of view rather than to assume a researcher's position and defend it. Debates when undertaken with spirit can greatly enliven a class and, at the same time, make areas of contention transparent. Unfortunately, our students were inhibited by the activity. Hence, the debate was replaced with a more practical class activity: that of demonstrating how the criteria being used to judge the students' papers derive from the writing standards and conventions of professional engineers.

To find additional ways to give students feedback on their writing and to help them assume responsibility for their work, this year's assignment included an incentive for taking drafts to Northwestern's Writing Place, the peer tutoring center. A few groups took advantage of this resource, and their papers were in most cases improved. We intend to encourage greater use of this resource in the future.

*Preliminary systematic analysis.* In 2003, a more thorough, and less potentially biased, analysis of the papers was begun to determine if an improvement can be objectively quantified and to see how the improvement, if one existed, mapped onto the specific learning goals we had targeted. The research team is investigating the following questions:

- Q1 – Where do undergraduate and graduate students begin the quarter in terms of their writing skills?
- Q2 – What is the slope of improvement for undergraduates in their writing from the first paper (T1) to the second (T2)?

- Q3 – How do the papers written in Year 5 (2003) compare to those in earlier years? And what is the effect of the intervention?

Preliminary analysis began with two independent coders scoring 16 papers to answer Q2, using a scoring rubric that divides the writing skills into two categories: lower and higher level thinking skills:

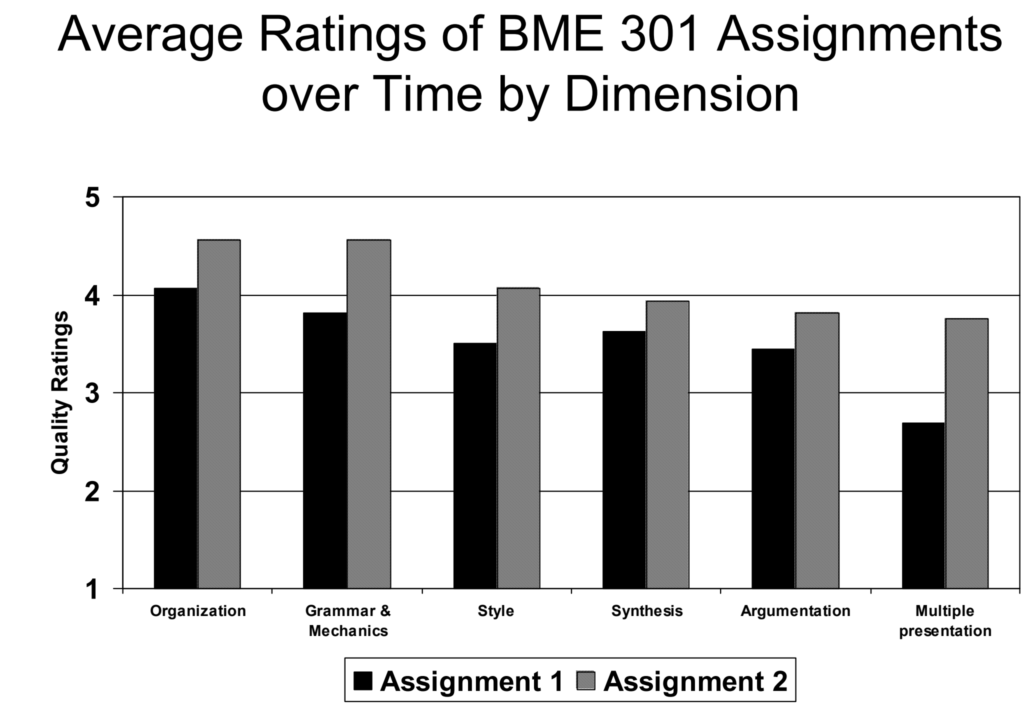
Lower Level Skills

- Tables, figures, equations: yes/no
- Organization
  - Divides information into useful categories and/or paragraphs
  - Effectively use headings and sub headings
  - Subdivides long sections
- Grammar and Mechanics
  - Proper referencing (in bibliography and body of text)
  - Errors in usage and grammar
- Style
  - Avoids repetition and narrative
  - Avoids lengthy sentences
  - Is easy to read
  - Uses words precisely

Higher Level Skills

- Synthesis
  - Draws on literature
  - Integrates ideas
  - Combines and summarizes evidence from other sources
- Organization/argumentation
  - Makes a clear argument
  - Provides evidence for claims
  - Considers alternate viewpoints
  - Provides rationale for paper
- Presentation of Information, Concepts, and Equations in Charts and Figures
  - Effectively utilizes multiple ways of presenting information

Papers were scored following the rubric on a scale of one to five, with five representing higher quality work. Ratings were evaluated for inter-rater reliability using an intra-class correlation coefficient. This measure was chosen because it provides an accurate index of agreement between coders and within categories, while not being influenced by the correlation between variables.[10] The overall intra-class correlation coefficient was 0.87, demonstrating a high level of agreement between coders. Ratings on individual dimensions ranged from 0.51 to 0.96, but all but the smallest coefficient fell above 0.69. Ratings for all dimensions were averaged across the two coders and used as the means by which to assess changes over time.




Note: Scale is 1 to 5 with higher numbers representing greater quality

Figure 1: Changes in student writing proficiency from assignment 1 to assignment 2, based on scoring of student papers by two independent coders.

*Preliminary findings and discussion.* Examining the relative change from paper to paper showed that students demonstrated improvement over time on all dimensions (see figures 1 and 2). Average gains were typically greater on lower level skills—grammar and mechanics, style, and organization—despite the fact that students started the term with greater mastery of them. This suggests that, given the opportunity to practice their writing, and being reminded of the importance of writing in engineering, students can tap into capabilities they have practiced in the past and improve in those areas, possibly with less instruction.[11]

In the higher level skills area, students were much more likely to utilize multiple methods of presenting information in the second paper, a finding that may reflect their growing understanding of how engineers communicate through multiple media. However, gains in synthesis and argumentation were more modest (Figure 2). Moreover, because of the relative lack of agreement between raters on the "synthesis" dimension (0.51 listed above), the degree of change on the synthesis measure should be interpreted with caution. The smaller gains in synthesis and argumentation suggest that students need more help to master these higher level skills, which are essential in biomedical engineering. This may be achieved through increased exposure to these concepts and to more models from which to work. In addition, next year's assessment might include finding out what students know about synthesis and argumentation coming into the course.

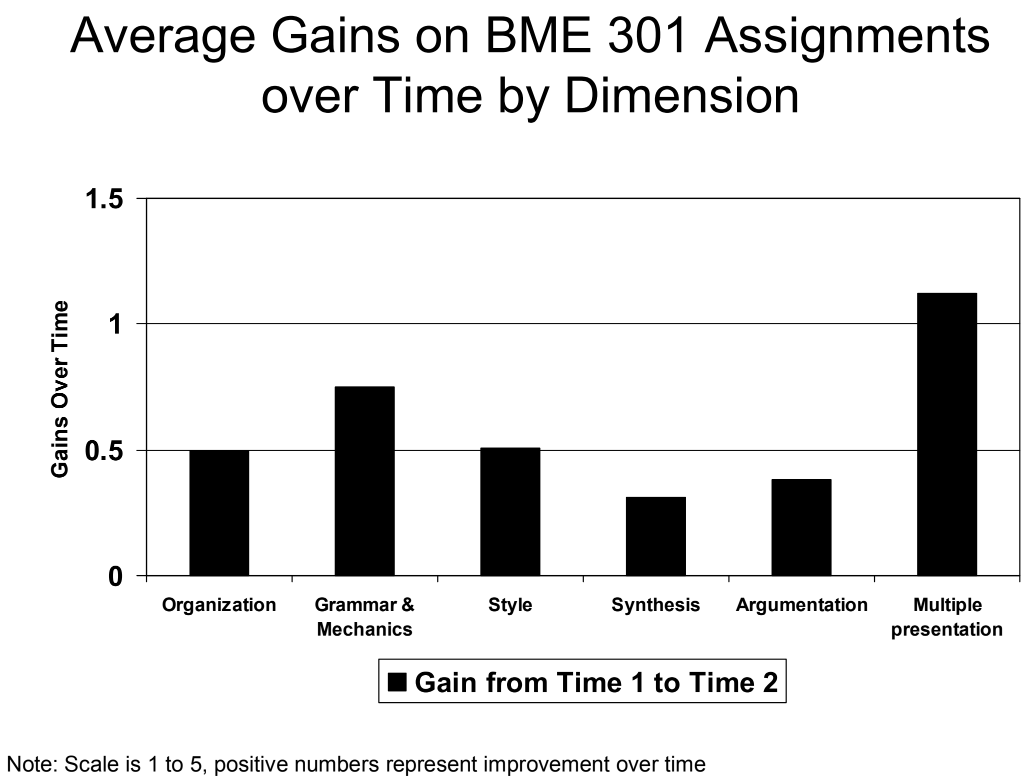



Figure 2: Gains in student learning from assignment 1 to assignment 2, based on scoring of student papers by two independent coders.

A formal analysis of the writing improvement has some limitations. For example, since we are trying to measure improvement in skills that are generally assessed subjectively and that are being observed in an educational setting, we cannot control for every factor, such as the fact that, as in most writing assignments, the second assignment in BMD ENG 301 differs from the first. If students found the second assignment easier, that might account for some of the improvement. Moreover, because it was difficult for coders to remain unaware of the time of the assignment, they might have been biased in favor of an expectation of improvement. As we continue the analysis, we will use historical controls and additional comparison groups in an effort to isolate the true cause of the observed improvement in writing. In addition, we will compare the systematic quantitative analysis to the holistic analysis more widely used in composition pedagogy.

Despite these limitations, the initial quantitative analysis lends credence to the instructor's impression that improvement does occur between assignment 1 and assignment 2.

## Conclusions

This study shows that communication instruction *can* be successfully incorporated into a junior-level BMD ENG class in a practical and efficient way that utilizes minimum resources. Integration of writing can be accomplished by emphasizing specific teachable, measurable outcomes, an approach consistent with the new outcomes climate emphasized in EC2000. Anecdotal evidence and preliminary assessment of writing improvement suggest that students have entered the class with room to improve in writing, justifying the need for an exercise like the one we have designed, and that the assignments are indeed helping students improve their writing competency in biomedical engineering. That the students demonstrate measurable improvement in most categories tested suggests that the second assignment was worthwhile. Nonetheless, if a second assignment is offered, then it makes sense to aim at seeing a more significant improvement in the higher level writing skills areas such as synthesis and argumentation, skills that are crucial for practicing biomedical engineers, or, in VaNTH terminology, for adaptive experts in biomedical engineering

Our immediate goal is to see whether the changes observed in our preliminary analysis are supported when we analyze data collected in previous years. If so, we will include new classroom exercises next year that seek to improve student learning in the higher level skills. In the meantime, we encourage others in upper-level engineering classes to offer students writing experiences that target the specific communication and critical thinking skills they will need in their professional lives.

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