Promoting Advanced Writing Skills in an Upper-Level Engineering Class

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ABSTRACT

This paper summarizes the design and evaluation of an instructional approach aimed at improving the writing skills of a group of undergraduate engineering students. We sought to determine whether student performance in difficult writing skills such as argumentation and synthesis could be improved by integrating a single writing exercise into an upper level engineering course. In designing the exercise, we relied heavily on recommendations for best practices from the learning science community, specifically those codified in the National Academy text *How People Learn* [1]. We found reliable improvement in student performance in many of the areas targeted, demonstrating that the approach taken was effective. Since we modified the exercise a few times before meeting our objectives for student learning, we could compare the effectiveness of different implementations of our approach. Our success and failures provide guidance for others seeking to improve the competence of engineering undergraduates in writing.

Keywords: *How People Learn*, role play, writing

I. INTRODUCTION: APPROACHES TO WRITING THROUGHOUT THE CURRICULUM

Since its inception in the 1960s and 70s, the Writing Across the Curriculum (WAC) movement has promoted the idea that writing should be taught as a mode of learning and not merely a means to remediate deficiencies in writing skill. Before, instructors in English assumed responsibility for student writing, generally through freshman composition courses [2–4]. However, as educators came to pay more attention to the relationship between language and learning, writing gained acceptance as an integral part of learning for all disciplines. The traditional approach of instructing students how to produce written text (e.g., transcribing language in written form, learning spelling and grammatical conventions, learning the principles of good style by examining exemplary models) was replaced by an approach that included a variety of cognitive activities such as planning, translating, and reviewing written text to satisfy communication needs such as purpose and audience [5]. WAC programs grew out of pioneering efforts at such schools as Carleton College, Beaver College (now Arcadia University), Michigan Technological University, and George Mason University. Supported by faculty workshops and grounded in learning science theory, WAC is embraced now by schools at every level. Writing intensive courses may be found in such disparate areas as history, sociology, economics, biology, and even mathematics. WAC and WID, for Writing within the Disciplines, have become familiar terms, and books about what constitutes good writing as a professional in specific disciplines have proliferated [6–9]. Thus, faculty members at many schools, even at research universities where WAC programs have not always been supported institutionally [10], have benefited from WAC practices and now consider it their responsibility to help their students improve at writing.

Engineering is certainly one field where proficiency in written communication is valued [11]. ABET EC2000 mandates that mastery of skills such as written communication, teamwork, and design be acquired progressively throughout the undergraduate curriculum [12]. Since 1996, the engineering school at Northwestern University has integrated writing instruction thoroughly into a required freshman design course taught jointly by writing instructors and engineering faculty [13, 14]. In recent years, written communication has also been included vertically in Northwestern's design curriculum in the Institute in Design and Engineering Applications [15]. At Rice University, the Cain Project in Engineering and Professional Communication offers communication instruction integrated into the curriculum through courses, workshops for faculty and students, online resources, and other support [16]. At the Massachusetts Institute of Technology and a related international consortium, communication resources are offered through their CDIO (Conceiving–Designing–Implementing–Operationalizing) initiative [17]. The NSF-funded VaNTH (Vanderbilt-Northwestern-Texas-Harvard/MIT) Engineering Research Center in Bioengineering Educational Technology has also developed workshops and a taxonomy of professional skills designed to help engineering educators clarify learning objectives as they design integrated communication assignments and work across departments to coordinate integrated instruction [18]. Many similar efforts are underway elsewhere.

Much of the research in engineering writing has focused on the pedagogical approach taken. Thompson et al. [19] studied interactive communication among learners, peers, and non-peers and encouraged students to take responsibility for their own learning, finding that when undergraduates talked to other people about

their research, they improved their skill at problem-solving as well as their ability in written, oral, and graphical communication. Jensen and Fisher [20] studied how the evaluations that students received enhanced their writing: comparing the effectiveness of reviews received from peers and those received from teaching assistants and instructors on laboratory reports, they determined that peer-evaluated students performed better. Some research has also focused on sociological factors that influence effective writing in engineering. Two ethnographic longitudinal studies led Winsor [21, 22] to conclude that, for effective communication, students must learn about the rhetorical nature of engineering writing, particularly how power relationships influence and are influenced by writing in hierarchical organizations.

In spite of the movement to incorporate student writing contextually in courses within one's discipline and the research supporting this endeavor (succinctly summarized by Bazerman et al. [4]), faculty are often on their own when it comes to designing integrated writing instruction. Even those faculty members who appreciate the merit of offering writing in content areas may be reluctant to add writing exercises because of the additional work such exercises entail. Many faculty members are also concerned about what they might have to remove from a course to make room for a writing exercise. In addition, some engineering faculty may be unconvinced about the effectiveness of integrating writing instruction into their classes since most assessment of learning in WAC programs and of the programs themselves has been qualitative rather than quantitative [4]. In fact, many factors contribute to faculty resistance to incorporating writing exercises into content courses for a discipline [10, 23].

In this paper, we describe the results of one attempt to improve student writing in a junior and senior level biomedical engineering course in neural systems physiology. The strategy we employed was to assign one or two team-based research papers per year in the course. Although the assignments typified a WAC approach and accepted WAC assumptions about the usefulness of teaching writing within disciplines, we found it necessary to optimize the instructional environment before the learning objectives of the instructor could be met. It is likely that this experience is a common one faced in instructional design and thus of general interest. Here we summarize the characteristics of our study participants, the design process and reliability issues of our study instrument, and the analysis. After presenting the findings, we discuss the study implications followed by the lessons learned from the 2005 intervention.

II. THE STUDY CONTEXT: GENERAL COURSE DESCRIPTION AND PREVIOUSLY REPORTED FINDINGS

As reported in Troy et al. [24], writing assignments were added to a junior/senior course in neural systems physiology that was being redesigned as part of the VaNTH effort to improve biomedical engineering instruction in physiology [25]. Additionally the aim was to fill a gap in the biomedical engineering curriculum at Northwestern University. As previously noted, all engineering students at Northwestern receive substantial instruction in written technical communication during their first year. Biomedical engineering majors also receive significant instruction in engineering writing as seniors in required courses. However, exposure to writing as engineers between freshman and senior years was less controlled. Adding the writing assignments to a core course in systems physiology ensured that all students in the biomedical engineering

undergraduate program would experience continuity in training in written communication that is in line with EC2000 recommendations, while still focusing on learning crucial content material.

Teaching and learning in the course takes place in three one-hour lectures and one one-hour discussion session per week, along with three laboratory exercises and five homework assignments. The quarter-length (11 weeks) course is given once per year. Approximately half of the eleven weeks are devoted to discussing the organization of the nervous system at the systems level. Emphasis is on the somatosensory system, including pain, the visual system, and the motor system. The other half of the course is devoted to discussing the structure of the neuron, its interaction with glial cells, its membrane properties, including the action potential, passive and active propagation of neural signals, and synaptic processes. The required textbook is Purves et al., *Neuroscience* [26], used in conjunction with the simulation software package Moore and Stuart, *Neurons in Action* [27].

Since 1999 students in the course have been asked to write team-based research papers that force them to explore the literature in neural systems that go beyond the textbook. Emphasis is placed on helping students work collaboratively within an authentic context. The research topics selected (one or two per year) were ones where biomedical engineers have made significant contributions to neuroscience. One topic fit well with the half of the course devoted to the cellular properties of neurons. The topic was the currently unresolved question of how neurons encode information. Students wrote papers on this topic every year. The other topic fit well with the half of the course devoted to neural systems. In different years, this paper concerned either the restoration of neural function by biological or synthetic replacement (1999, 2003), the representation of images by the visual system (2000, 2004), or the control of locomotion by neural circuits (2000). Students were given the criteria on which their written work would be graded in advance, and one or two class sessions were devoted to writing instruction. The writing exercises were done in groups of three to six students.

All instructional modules developed by VaNTH, whether for mastery of domain skills or core competencies, aim to help 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 more comfortably handle ambiguity, solve novel problems, and communicate at a high level. One design criterion is organizing learning exercises around challenging topics with open-ended solutions like those described earlier. In developing the communications module reported in this paper, the instructor also used the VaNTH taxonomy of core competency skills in writing [28] to define five specific learning objectives for accomplishing the goal of helping students improve their capability in written technical communication:

- writing concisely
- using figures, tables and equations, along with 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

The instructor chose these five objectives in 2003 because an analysis of student papers from earlier runs of the writing exercise (1999–2002) revealed student deficiencies in these areas.

In the 2003 offering of the course, students wrote two research papers, so we assessed the change in student writing from papers

one to two. After the course concluded, the student papers were evaluated by trained, independent coders using a rubric that had been developed to assess the learning objectives noted above. For the most part, student writing was assessed with regard to two over-arching dimensions, which we called *lower level skills*, such as grammar and mechanics, and *higher level skills*, such as synthesis and argumentation. The rubric used to score the papers (Appendix A) broke these broad dimensions into sub-categories that were easy to define and measure. We found that students showed more improvement over time in the lower level skills [24]. Average gains were typically greater on grammar and mechanics, style, and organization, despite the fact that students started the term with greater mastery of them. While these are necessary skills for proficient writing, an additional and more important goal for us was to improve students' higher level writing skills; that is, to help students develop the ability to synthesize research findings in a meaningful way, represent data effectively in graphs and tables, and craft a coherent, persuasive argument. These skills are precisely what professional engineers need in order to write effectively in academia and industry.

III. GOAL OF THE CURRENT STUDY AND REVISED INSTRUCTIONAL APPROACH

Writing instruction in the 2005 offering of neural systems physiology was designed to address the shortfall between learning objectives and outcomes discovered in our analysis of the 2003 papers; the goal was specifically to help students improve in writing areas like synthesis and argumentation. Since the course was being re-designed under the auspices of VaNTH, which encourages the use of a *How People Learn* (HPL) pedagogical approach [1], a renewed effort was made to apply HPL techniques more deliberately to the writing interventions.

To design an instructional approach that would more specifically target the *higher level* writing skills desired by the instructor, our faculty team returned to the core principles that underlie all VaNTH instructional modules. As mentioned previously, all of these modules, or segments of courses, are designed around *challenges* intended to engage the students in an authentic disciplinary activity, and all modules should reflect the following four key dimensions [1].

- *Knowledge-centeredness:* to help students (a) *learn with understanding* by organizing knowledge around key concepts and (b) move from novice to expert problem-solving methods.
- *Learner-centeredness:* to (a) take into account the knowledge, skills, preconceptions, and learning styles of all students and (b) start with what students know when they enter the class.
- *Community-centeredness:* to (a) encourage students and faculty to learn from one another and (b) situate learning within real-world (authentic) challenges.
- *Assessment-centeredness:* to (a) provide frequent opportunities for students to make their thinking visible and receive appropriate feedback and (b) revise teaching and learning activities after measuring student learning.

Analysis of the assignments and student papers from 2003 within this context suggested that even though the instructor had designed the challenges around authentic issues in the field and had tried to help students see how he, as an expert, would approach the problem, the students did not sufficiently embrace the challenge or see the importance of synthesizing information from different sources in order to develop an argument. We believed we could improve student learning in the areas where we had failed previously by making two key changes. We would make the instruction more learner-centered and more community-centered by (a) recasting the challenge as a well structured role-play and (b) replacing one of the two class sessions devoted to writing with a more student-centered event.

A. Re-Casting the Challenge as a Structured Role-Play

Our first change in the writing intervention was to modify the challenge so that students could more easily imagine themselves in a professional role. Although the assigned research topics were based on authentic, unsolved problems in the field (how information is encoded in the brain, whether neural function can be recovered biologically or artificially, etc.), we believed that the students were unable to imagine themselves as researchers who cared about these problems because the material was difficult to master and the researchers who confront these issues are much more experienced than juniors and seniors in college. This speaks to the problem of engagement for students, who tend to be influenced in their writing by the classroom setting and the knowledge that writing assignments are part of the course grade. Herrington [29] found that learning to write in chemical engineering courses was difficult for students because they had to learn not only the conceptual activities that dominate the discipline but also the roles of the writer and audience and the purpose of the written document. In a school setting, students know they are writing for the instructor, and if the material is difficult for them to master, they tend to see their research papers as just another assignment to complete for a grade. In our assignment, the complexities of the neural coding issue contributed to the students' difficulty in synthesizing information from different sources. Thus, the assignment was frustrating for students, and not sufficiently *learner-centered* for undergraduates.

Herrington proposed structuring classroom settings to help enact a professional context. Following this line of thinking, we recast the challenge as a scenario in which the students were to see themselves as entry-level graduate students—a more attainable goal—working in one of two biomedical research labs. In the scenario, each lab espouses one of the two major theories about neural coding: (1) that neurons encode information in the rate at which they discharge action potentials and (2) that neurons encode information in their pattern of action potentials discharged. We placed one-half of the student groups randomly in a lab that ascribes to the former theory and the other half in one that ascribes to the latter theory. In both cases, we gave the students a more easily imaginable and streamlined task: we asked them to imagine that they were helping the lab director prepare for a speech at a prestigious conference. The two labs view each other as competitors and thus each director is keen to be well versed in the arguments that the other might present. See Appendix B for the entire scenario and related assignment.

We hypothesized that students who could see themselves as a young member of a research team in someone's lab would write more effectively because they would better understand their role. Moreover, this role dictated the side of the issue they should argue in the debate. Thus, the role-play made argumentation more prominent in the exercise at the same time that it made the writing assignment more learner-centered and more community-centered. All of

these changes, we hoped, would achieve the main goal of HPL interventions: to help students learn with greater understanding.

B. Using a More Student-Centered Event to Teach Argumentation and Synthesis

In 2003 and 2004, two class sessions were devoted to writing; however, as we reviewed the course from a new perspective, we decided these classes were not sufficiently learner- or community-centered. In one class, the instructor showed students models of professional articles that were effectively organized, well argued, and properly documented. This was a knowledge-centered class in which the instructor, using himself as a model of the *expert* writer, showed students how he would approach the research and begin to develop a draft. We decided to retain this class session in 2005, which uses a *cognitive apprenticeship* approach to teaching [30], but to select readings for the class session that would more dramatically illustrate stronger and weaker examples of argumentation.

In the second session from 2003 and 2004, students were shown examples of information that was synthesized in professional articles. *Synthesizing literature* was explained to students by explicating its difference from *analyzing* the literature. The concepts were presented in mini-lectures, followed by time for students to discuss models and their own paper planning in small groups.

While the class sessions were meant to be discussion sessions rather than lectures, students rarely asked or responded to questions. The small group discussions also lacked engagement. As a follow-up to these class sessions, students were asked to edit drafts of their peers' papers and to get feedback on their drafts from the university's writing center. However, few groups took advantage of these opportunities, even though a reward was offered in the form of bonus points.

In 2005, since the instructor did not believe he could devote additional class time to writing instruction, we needed to make this second class session much more interactive. We decided to structure it as a mini-presentation in which two randomly selected groups (one from each side of the debate) would present their arguments to the rest of the class. Following their presentations, the teaching assistant who moderated the debate would hold a question and answer session. This event was scheduled to take place a week before the final papers were due so that students would be motivated to attend, ask questions, and revise their drafts following the session. The instructor did not attend in case his presence would be an inhibiting factor. However, beforehand, the teaching assistant was made fully aware of the learning objectives of the exercise, particularly the importance of argumentation and synthesis. We hoped that this structure would encourage more peer-to-peer learning.

One researcher attended the class sessions to observe. Below is a summary of this debate and discussion session, showing much greater involvement on the part of the students.

Presenters discussed their groups' main arguments, supporting evidence, and counter evidence. After each presentation, the teaching assistant posed questions to the group members and commented on the arguments. Typical questions and comments included the following:

- "What is your main point in this paper?"
- "Is this [paragraph/section] one example of your point or everything you want to say?" (The teaching assistant explained that a good argument requires more than one example or experiment for supporting evidence.)

- "It would be better to combine (synthesize) the results from several experiments."
- "You need more than one experiment to support this idea."
- "Where did you learn all of this?"

After the presentations, students asked the teaching assistant specific questions about argumentation and documentation:

- "Should we mention the positive and the negative sides from all perspectives?"
- "Do we use N-citation or another type?"
- "Do we need to include everything about the experiment in the paper or just the conclusion or results?"
- "Do we have to say Temporal Coding is completely wrong?"
- "What if I list four experiments for Rate Coding and four experiments for Temporal Coding? Is this a good format?"

Students often responded to one another's questions and engaged in a dialogue where they identified strategies to better synthesize the literature and write a convincing argument. In those discussions, each student had the chance to talk about his or her specific needs and ask questions that we as educators might not have thought about. For example, one asked whether there is a limit to the number of experiments a good argument may involve. For questions like these, students received feedback from the teaching assistant and from their peers. They left the session looking more confident about the writing assignment.

For a few discussion points, no consensus was reached, e.g., whether to summarize all the evidence from all points of view or whether to hide some of the opposing evidence while highlighting all the supporting evidence. After students discussed this issue, the teaching assistant commented that talking about the opposing evidence may help convince the reader that the writer is knowledgeable about the subject, which in turn helps to promote the validity of an argument.

In summary, linking the class format to the scenario and having students present their ideas orally in the group setting made the assignment more learner-centered and more community-centered.

IV. Methods of Inquiry

To assess the effectiveness of the new, more deliberately HPL interventions, we analyzed and compared the group papers written in 2004 and 2005. The first year reflected what might be considered the less HPL-inspired approach to teaching writing, similar to what was described in Troy et al. [24]. The 2005 effort reflected a targeted attempt to improve the teaching of higher level skills and was based upon what appeared to be lacking after assessment of the 2003 data.

A. Participants

As mentioned earlier, study participants were the undergraduates enrolled in an upper level Biomedical Engineering course at Northwestern University in 2004 and 2005. For each year, there were 10 groups of students and thus ten papers. Each group comprised three to five students. All students were asked to consent to participate in this study. Because a few individuals did not provide consent to review their in-class materials, we eliminated one paper from 2004 and two papers from 2005. Overall, there were nine papers from 2004 and eight papers from 2005 in our analysis.

B. Instrument

As in our earlier study, we used a scoring rubric to assess students' writing skills, but the rubric was more detailed. The rubric covered seven areas: (a) organization and formatting, (b) mechanics, (c) style, (d) clarity and quality of content, (e) synthesis, (f) argumentation, and (g) visual thinking (charts and tables). For each of these seven areas, papers written in groups were rated on a five point scale (1 to 5). The maximum possible score for a paper was 35 and the minimum score was seven.

1) *Rationale for the rubric division*: To maintain some continuity with the rubric of our previous study, we grouped the first three areas, which students seem to find easier to improve, as *basic level writing skills* and the later four, which seem to present more difficulty for students, as *advanced level writing skills*.

2) *Inter-rater reliability*: To improve the inter-rater reliability of the rubric, we put it through several iterations based upon a small sample of the papers. Three researchers—a learning scientist, a cognitive psychologist, and a writing instructor—in addition to another outside person whose field of study is not engineering, blind-scored the papers. We also utilized the engineering instructor's grading for the papers in our comparisons. Based on the weaknesses in some of the comparisons, we revised the sub-scores of each component in the rubric, adding more detailed explanations, and then re-scored the papers. With the revised rubric, we achieved a high correlation ($r = 0.89$) among the three researchers' ratings. All scoring was done blind to the class year of the paper.

C. Analysis

After achieving a sufficient level of inter-rater reliability, two of the researchers read the papers from 2004 and 2005 and blind-scored them. The correlations of those two researchers' ratings among the rubric components were between 0.71 and 0.96. Table 1 lists correlation coefficients. Because they were fairly high, we averaged the two raters' scores for our analysis.

We compared the averaged student paper scores of 2004 and 2005 data using the SPSS software package. Several analysis of variance measures (ANOVA) were computed to determine if the student writing skills in 2005 differed from those in 2004. This is a different strategy from the one described in Troy et al. [24] in that it compares groups of different students as opposed to the same students on two successive occasions. While this approach was taken simply because it was all that was possible, given the new ver-

Rubric component	Correlation coefficient
Organization and formatting	0.84
Mechanics	0.86
Style	0.86
Clarity and quality of content	0.76
Synthesis	0.87
Argumentation	0.71
Visual thinking: charts and tables	0.96

Table 1. Correlations between rater 1 and rater 2 across the rubric components.

sion of the course, it helps to rule out the possible explanation of practice effects accounting for differences. Additionally, it more realistically reflects how much writing, and thus improvement, can consistently be expected in a course such as this.

V. Findings

Given the small sample size and resulting low statistical power, ANOVA results were supplemented by measures of Effect Size (ES), representing the standardized difference between groups in standard deviation units. While it is advisable to interpret ES in light of established norms in a particular domain, one suggested rule of thumb suggests that 0.2 should be considered small, 0.5 considered medium, and 0.8 considered large effects [31]. ANOVA results revealed that students who received the 2005 intervention performed better than students who received the 2004 intervention in the following components of their written reports: "Organization and Formatting," $F(1, 16) = 9.23$, $p < 0.01$, ES = 1.50, "Style," $F(1,16) = 5.31$, $p < 0.05$, ES = 1.13, "Clarity and quality of content," $F(1, 16) = 9.65$, $p < 0.01$, ES = 1.53, and "Argumentation," $F(1,16) = 14.46$, $p < 0.01$, ES = 1.85. Differences on one component, "Synthesis," approached statistical significance but did not meet the $p < 0.05$ minimum criterion, $F(1, 16) = 4.01$, $p = 0.064$, ES = 0.99. Students' paper scores were not found significantly different in the "Mechanics," $F(1,16) = 0.27$, $p = 0.61$, or "Visual thinking (charts and tables)," $F(1,16) = 0.69$, $p = 0.41$, components of the rubric. Figure 1 represents the means of students' paper scores for each component of the rubric.

VI. Discussion

In 2004 and 2005, HPL strategies were used more deliberately to help improve students' engineering writing skills. As discussed earlier, the 2004 instruction encompassed an in-class presentation and guidance from the instructor. Students performed relatively well after receiving this instruction, but they improved more in "lower level" writing skills than in "higher level" skills such as synthesis and argumentation.

Hence, in the design stages of the 2005 intervention, we focused on the advanced level writing skills. In 2005, we implemented a different strategy, described above, more fully informed by the *How People Learn* framework [1]. Because our aim was to help students improve advanced writing skills such as synthesis and argumentation, extra emphasis was placed on learner- and community-centeredness in the instructional strategy to encourage student engagement with the challenge and with each other.

Our results suggest that the "HPL informed approach" benefited students in a variety of ways. Although not all differences were statistically significant, which should be expected from such a small sample, improvements were seen on every dimension, including lower level skills. The largest gains appear in the area of argumentation (ES = 1.85) and the smallest in mechanics (ES = 0.25). Generally, the larger gains are seen in the areas described above representing more advanced skills, with ES of 1 or higher on synthesis and argumentation. This represents quite large differences between years, with the high numbers suggesting the strength of the new approach.
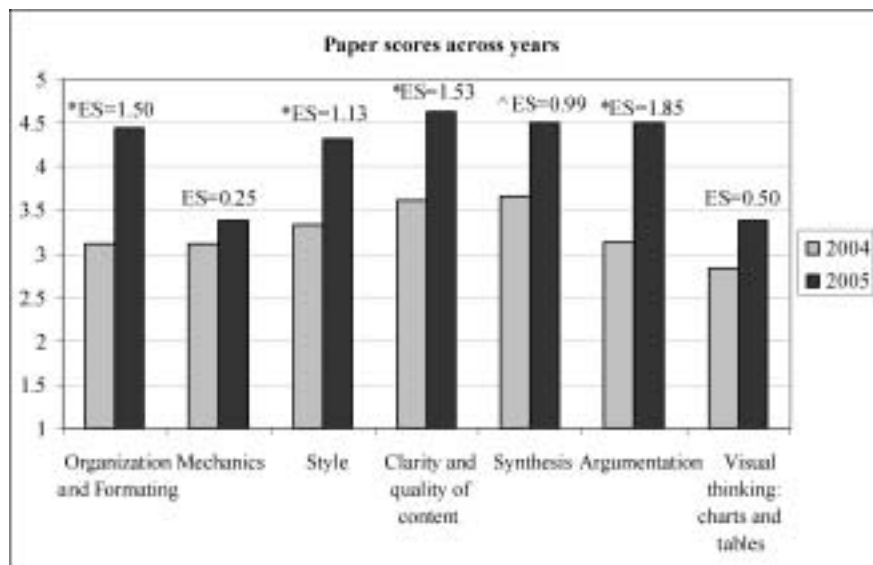
Figure 1. The mean scores of students' papers across 2004 and 2005 (ES stands for Effect Sizes. "*" indicates that the p values were less than 0.05. "^" indicates that the p value was very close to 0.05).

We believe that the learner-centered and community-centered emphasis of the exercise was responsible for helping students overcome the difficulties posed by the challenging goal of developing advanced writing skills. Argumentation and synthesis seem to require illustrative examples and personal commitment. For example, in order to synthesize the literature, students need to know the content very well but also to develop strategies for illustrating ideas and statements in a concise and meaningful way. Without knowing specific techniques, students may not be able to synthesize the literature effectively regardless of their content mastery. Yet, writing about that literature is an ideal way to learn how to synthesize it because, as Emig [32] noted, writing is a unique way of learning that is inherently integrative and requires the use of both analysis and synthesis. Similarly, writing good arguments requires not just knowledge of content but a convincing style augmented with the logic of argumentation. Role-playing, personal commitment, and peer-to-peer learning (reader feedback) become crucial in writing good arguments. The techniques for visual thinking also require practical illustrations and perhaps a more focused instructional strategy, something that we may not have emphasized sufficiently since only a modest improvement, which did not reach statistical significance, was observed in this area. Alternatively, it may be that our rubric was not well designed for measuring growth in visual thinking or sufficiently coordinated with our pedagogy.

Perhaps visual thinking as a category needs to be subdivided, with one part measuring students' understanding of conventions and best practices related to data graphics (e.g., where labels belong, line thickness, style of graphic presentation, how to discuss the point of a graphic in the text), and another part measuring whether students understand when and how to use a graph to present evidence in an argument or to write concisely about data that would be confusing if presented in text. If so, the first category might be thought of as a *lower level*, mechanical skill, whereas the second would be more closely related to clear writing and effective argumentation. Neither our instruction nor our analysis of student papers took this complexity about visual thinking into account. In fact,

our rubric prioritized students' understanding of the mechanical and conventional handling of graphics, which was not emphasized in class and thus may partially account for the lack of improvement in this category.

Similarly, mechanics in writing were not stressed in class, and students may not have put much of an effort into making their final drafts as professionally finished as possible, especially since they would not be publishing these papers. If this hypothesis is true, then the student behavior mimics the behavior of most professionals, who do not overly worry about mechanics when they are not publishing their work. Thus, we do not find the lower numbers in mechanics to be a concern.

VII. CONCLUSION

In summary, this study suggests that an HPL approach to pedagogy in a WAC or WID context is just as beneficial to promote learning in writing as it has been shown to be for mastery of science, mathematics, and engineering. As WAC researchers have shown, and our previous experience [24] confirms, simply integrating writing instruction into a disciplinary course like systems physiology is insufficient to help students acquire the more advanced writing skills that they will need as experts in a professional field. Rather, to teach higher level skills like synthesis and argumentation, instruction must be learner-centered and community-centered. Moreover, writing instruction benefits from the assessment-centered dimension of an HPL approach. Assessment of student performance in the early years of the exercise laid the groundwork for formulating well-defined learning objectives. Analysis from the study of Troy et al. [24] showed us where our instructional intervention was failing, and analysis of the papers from 2005 has shed considerable light on how we may need to refine our teaching and assessment of visual thinking in writing.

Following are some lessons learned from the 2005 intervention about teaching advanced writing skills:

- *Faculty must do more than embed writing assignments into their class.* They need to create challenge-based assignments, like

the scenario in our 2005 assignment, which are well suited to a student's developmental abilities and sense of identity. By the time students write papers in our upper level courses, they have spent 14 years developing their identity as a student. If we want them to develop the writing skills that are useful for a professional, we have to help them imagine themselves in a professional role. If we make the leap too great in an assignment, students will not be able to accept the challenge. If they cannot imagine the assignment's authenticity, they will fall back on what they do know: how to complete an assignment for a due date in school.

- *The writing assignment must be given with time for students to receive feedback, reflect on their learning, and revise their drafts.* Feedback need not always be written and need not be individual, but it must be well timed. Students are most open to writing instruction—and most able to verbalize their preconceptions and misconceptions—when they are in the middle of working on a paper. In our 2005 intervention, students formulated their own questions about the writing assignment. We believe this had a direct bearing on the improvement we noted in the papers of 2005 over the ones produced in 2004.

- *Writing requires an interactive, coaching pedagogy—like that advanced by HPL techniques—because writing mastery is both conceptual and performance-based.* Students do not really understand writing until they can do it, and "doing it" has just as much, if not more, to do with understanding key concepts such as audience, purpose, and context as with mastering skills in style, conventions, and technologies.

We believe accomplishing the HPL framework with the three strategies outlined above—the use of embedded assignments, adequate time for student reflection, and interactive and coaching pedagogy for teaching writing—will encourage students to improve their writing skills. Instructional designs similar to the one presented in this paper can be implemented in other learning environments. For example, in teaching research ethics in a science course, students in groups can be confronted with real ethical dilemmas on the use of human and/or animal subjects for scientific research and asked to present their cases to one another in an interactive manner. If students are given useful feedback and time to reflect upon it, they will most likely write more effective case summaries. Most importantly, writing instruction in upper level science and engineering courses can—and should—successfully target the skills and applications that students are unlikely to receive in general courses in English or composition. Writing needs to be taught both by writing instructors and writers in the disciplines.

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REFERENCES

[1] Bransford, J., A. Brown, and R. Cocking, *How People Learn: Brain, Mind, Experience, and School*, Washington, D.C.: National Academy Press, 1999.

[2] Bazerman, C., and D.R. Russell, (Eds.), *Landmark Essays on Writing Across the Curriculum*, Vol. 6, Davis, CA: Hermagoras Press, 1994.

[3] Townsend, M.A., "Writing Across The Curriculum," In A.C. Purves, (Ed.), *The Encyclopedia of English Studies and Language Arts*, Vol. II, 1994, pp. 1299–1302, http://cwp.missouri.edu/cwpinfo/aboutwac.htm.

[4] Bazerman, C., J. Little, L. Bethel, T. Chavkin, D. Fouquette, and J. Garufis, *Reference Guide to Writing Across the Curriculum*, West Lafayette, IN: Parlor Press, 2005.

[5] Galbraith, D., and G. Rijlaarsdam, "Effective Strategies for the Teaching and Learning of Writing," *Learning and Instruction*, Vol. 9, No. 2, 1995, pp.93–108.

[6] McMillan, V.E., *Writing Papers in the Biological Sciences*, Boston, MA: Bedford Books, 1997.

[7] Paradis, J.G., and M.L. Zimmerman, *The MIT Guide to Science and Engineering Communication*, 2nd ed., Cambridge, MA: The MIT Press, 2002.

[8] Miller, J.E., *The Chicago Guide to Writing about Numbers*, Chicago, IL: University of Chicago Press, 2004.

[9] Hedengren, B.F., *A TA's Guide to Teaching Writing in All Disciplines*, Boston, MA: Bedford/St. Martin's, 2004.

[10] Fulwiler, T., "How Well Does Writing Across The Curriculum Work?," in C. Bazerman and D.R. Russell, (eds.), *Landmark Essays on Writing Across the Curriculum*, Vol. 6, Davis, CA: Hermagoras Press, 1994, pp. 51–64.

[11] Shuman, L.J., M. Besterfield-Sacre, and J. McGourty, "The ABET 'Professional Skills'-Can they be taught? Can they be assessed?," *Journal of Engineering Education*, Vol. 94, 2005, pp. 41–55.

[12] Accreditation Board for Engineering and Technology (2006), *Engineering Change: A Study of the Impact of EC2000, Executive Summary*, http://www.abet.org/papers.shtml.

[13] Hirsch, P., B. Shwom, J. Anderson, G. Olson, D. Kelso, and J.E. Colgate, "Engineering Design and Communication: Jump-Starting the Engineering Curriculum," *Proceedings, ASEE Annual Conference and Exposition*, Seattle, WA, 1998.

[14] Engineering Design and Communication (EDC), Northwestern University, http://www.edc.northwestern.edu.

[15] Institute for Design and Engineering Applications (IDEA), Northwestern University, http://www.idea.northwestern.edu.

[16] Cain Project in Engineering and Professional Communication, Rice University, http://www.owlnet.rice.edu/~cainproj/about.html.

[17] The CDIO Initiative, http://www.cdio.org/index.html.

[18] VaNTH Engineering Research Center for Bioengineering Educational Technologies, www.vanth.org.

[19] Thompson, N.S., E.M. Alford, C. Liao, R. Johnson, and M.A. Matthews, "Integrating Undergraduate Research into Engineering: A Communications Approach to Holistic Education," *Journal of Engineering Education*, Vol. 94, No. 3, 2005, pp. 297–3007.

[20] Jensen, W., and B. Fischer, "Teaching Technical Writing Through Student Peer Evaluation," *Journal of Technical Writing and Communication*, Vol. 35, No. 1, 2005, pp. 95–100.

[21] Winsor, D., *Writing Like An Engineer: A Rhetorical Education*, Hillsdale, NJ: Erlbaum, 1996.

[22] Winsor, D., *Writing Power: Communication in an Engineering Center*, Albany, NY: State University of New York Press, 2003.

[23] McLeod, S.H., "Writing Across the Curriculum: The Second Stage, And Beyond," in C. Bazerman, J. Little, L. Bethel, T. Chavkin, D. Fouquette, and J. Garufis (eds.), *Reference Guide to Writing Across the Curriculum*, West Lafayette, IN: Parlor Press, 2005, pp. 79–86.

[24] Troy, J., P. Hirsch, H.D. Smith, and B. Yalvac, "Team-Based Written Communication Exercises for Biomedical Engineering Juniors: Where To Do It and What Works," *Proceedings, ASEE Annual Conference and Exposition*, Salt Lake City, UT, June 2004, http://www.vanth.org/docs/Troy.pdf.

[25] Troy, J.B. and R.A. Linsenmeier, "Physiology Instruction in Biomedical Engineering through the Vanth ERC: Optimizing the Delivery of Content," *IEEE Engineering in Medicine and Biology Magazine*, July/August 2003, pp. 80–87.

[26] Purves, D., G.J. Augustine, D. Fitzpatrick, W.C. Hall, A.S. LaMantia, J.O. McNamara, and S.M. Williams, (Eds.), *Neuroscience*, 3rd ed., Sunderland, MA: Sinauer Press, 2004.

[27] Moore, J.M., and A.E. Stuart, *Neurons in Action*, Version 1.43, Sunderland, MA: Sinauer Press, 2004.

[28] Core Competencies, VaNTH ERC, 2006, http://www.vanth.org/curriculum/curr_taxon_comm.asp.

[29] Herrington, A.J., "Writing in Academic Settings: A Study of the Contexts for Writing in Two College Chemical Engineering Courses," in C. Bazerman, J. Little, L. Bethel, T. Chavkin, D. Fouquette, and J. Garufis (eds.), *Reference Guide to Writing Across the Curriculum*, West Lafayette, IN: Parlor Press, 2005, pp. 97–121.

[30] Ben-David Kolikant, Y., D. Gatchell, P. Hirsch, and R.A. Linsenmeier, "A Cognitive-Apprenticeship-Inspired Instructional Approach for Teaching Scientific Writing and Reading," *The Journal of College Science Teaching*, Vol. XXXVI, No. 3, 2006, pp. 20–25.

[31] Cohen, J., *Statistical Power Analysis for the Behavioral Sciences*, 2nd ed., Hillsdale, NJ: Lawrence Erlbaum Associates, 1988.

[32] Emig, J., "Writing as a Mode of Learning," in C. Bazerman, J. Little, L. Bethel, T. Chavkin, D. Fouquette, and J. Garufis (eds.), *Reference Guide to Writing Across the Curriculum*, West Lafayette, IN: Parlor Press, 2005, pp. 89–96.

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APPENDIX A

Lower Level Skills
- Tables, Figures, Equations: yes/no
- Organization
  - Divides information into useful categories and/or paragraphs
  - Effectively uses 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

APPENDIX B

Scenario and Assignment for the Team-Based Research Paper, Fall 2005

The following story is fictional. It is an exaggerated but more or less realistic example of a situation that could arise in the professional life of an academic biomedical engineer.

Odd Number Groups

The National Academy is sponsoring a workshop on the topic of Neural Coding in Washington, D.C. Your new advisor, Dr. Wilson, has published a number of papers advancing the case that the messages carried by neurons are encoded in their spike trains in terms of *the rate at which they fire action potentials*. She has been asked to deliver a keynote speech making the case for neural rate coding. Although it is a great honor to be asked to make such a speech at such an important event in such a prestigious location, Dr. Wilson is anxious that she will not do herself justice and be embarrassed in front of her colleagues. At the root of Dr. Wilson's anxiety is the fact that her main protagonist, Dr. Smythe, will also be at the meeting, making another keynote speech advancing an alternative model of how neurons encode information. Dr. Wilson is concerned because Dr. Smythe is so respected in the field. After all, it is widely rumored that he will soon be inducted into the National Academy.

Dr. Wilson has asked your team to help her prepare her speech. She has chosen you, a recent graduate in biomedical engineering from Midwestern University, to be on the team because of your strong background in mathematics and engineering. What you are called upon to do is research the literature on neural coding, paying special attention to other models of neural coding than the rate code. There is no need for you to search out and read Dr. Smythe's papers; Dr. Wilson herself will look them over.

Even Number Groups

Meanwhile, over in Dr. Smythe's lab, preparations for his speech are also underway. Dr. Smythe has long promoted the view that neural messages are encoded in *patterns of action potential discharge*, and it is the case for such coding that will form the core of his presentation at the National Academy. Dr. Smythe is very keen to make a strong impression at this meeting. He has spent a lot of time over the years courting National Academy members and now that he feels he is on the verge of seeing the fruits of that effort, he does not want to let it all go to waste with a below par performance in the citadel he so earnestly wishes to grace with his membership. Dr. Smythe has been irritated ever since he found out that Dr. Wilson would be offering the opposing viewpoint. While he is quite sure that he has the sharper mind, one must worry about having an off day.

You are also a recent graduate of Midwestern University, with a B.S. in biomedical engineering. You chose Dr. Smythe's lab because it is renowned. Dr. Smythe has assigned you the task of making the case for the alternative rate coding hypothesis. He is determined to be ready for whatever curve-balls Dr. Wilson might throw out in her presentation. He has not asked you to look at Dr. Wilson's papers. He will review them thoroughly himself, but he would like you to research the rest of the literature for him. It is important that he be seen to have a full grasp of the field as it stands today.

Both Groups

It does not matter whether you like Dr. Smythe more than Dr. Wilson or *vice versa*; you must act professionally and not let your personal feelings weaken your resolve to do the best job you can. A library of neural coding papers has been provided on the course Blackboard website that you can use. You are also encouraged to search out your own sources. You are discouraged from relying too heavily on summaries you may find on the web. They often contain inaccuracies. People who are active in a research field rarely have time to write web tutorials. An important point of the exercise is to help you become familiar with original source material. You can download recent papers by accessing the library's electronic resources (http://er.library.northwestern.edu), but you will have to familiarize yourselves with the journal stacks in the library to find some of the classic papers.

Mechanics

For the homework exercise, you have been assigned to a group that will write a report making the case either "for neural rate coding" (even number groups) or "for spike pattern coding" (odd number groups). You should summarize the evidence *in favor of* and *against* your position, making the strongest case you can for your side of the argument. In reality, one would generally seek to write a balanced view of the debate, but since we are seeking to

hone your ability to write a convincing argument, the emphasis of the exercise is slanted in this direction. You have two weeks in which to finish the assignment (due October 26). You will score very well on the paper if you have found some additional sources other than those you were given (new original papers counting more than information from the web) and have effectively synthesized information from those papers into your group's argument for or against rate encoding. You will also be assessed on the completeness of your research, the strength of your arguments, the paper's overall organization, its clarity and grammatical correctness, and how effectively you have used tables and diagrams to communicate ideas that are difficult to explain with words alone.

Instructions for the paper

1) The paper should be written so that it has no more than five pages of double-spaced lines of text with one inch margins top and bottom, left and right. The five-page limit does not include a bibliography at the end, figures or tables. A title page does not count against the page limit. Use Arial 11 point as the font.

2) Use a consistent form of referencing when citing papers. When you refer to a multi-author paper, use either all names or et al. (e.g., Kumar, Smith, and Wu, 2002 or Kumar et al.,

2002). For two author papers, give both names. In the bibliography, all authors' names should be given for every paper.

3) You can scan figures from books and papers (or download pictures from the web) to include in your paper as long as they are cited appropriately. Bear in mind though that you should be using figures to make a point, not just to include them for their own sake.

On October 19, the full class-time will be used so that some groups (drawn at random) can make preliminary reports to the class on the case for and against rate coding.

Posted on Blackboard you should find some of the papers you are assigned. The assigned papers are listed in the document titled Homework 2 2005 Neural Coding Papers. All groups are expected to read the general papers and the papers assigned to their group. To access some of the papers, you will need to use the journal stacks in Northwestern University's Library. This is intentional. One objective of the exercise is to familiarize you with accessing original papers. You should be able to determine how to do this yourselves.

Also, posted on Blackboard are the following supplementary documents, intended to help you with technical writing:

- Rationale, Advice, and Scoring–Homework 2 2005
- Supplemental Document (Writing for Excellence)
- Guidelines for Writing an Effective Group Report

Scoring Rubric used to grade student papers from 2004 and 2005 (final version)

A. LOWER LEVEL THINKING/WRITING SKILLS	Note: For each level, assign only one score ranging from 1 to 5 (1 is minimum, 5 is maximum)

A1) Organization & Formatting

- Divides information into useful categories/paragraphs
- Effectively uses headings and subheadings (where needed)

5 = does all of these well; would not know how to tell writer to improve

4 = pretty good at paragraph level; uses topic sentences and/or transitional words; may use headings but not subheadings; paragraphs may be clear but too long, but still easy to move from one paragraph to another

3 = does about half of this right; may have good paragraphing but no headings

2 = paragraphs are hard to follow; paragraphs do not highlight a key idea; quality of paragraphing is inconsistent; hard to move from one paragraph to another; transitions are missing

1 = almost unreadable at paragraph level; very incoherent

A2) Mechanics

- Correct references in bibliography and body of paper
- Correct usage, punctuation, grammar

5 = correct, consistent references, used wherever reader needs a citation (text and figures); used throughout; usage, punctuation, grammar are excellent, 0-1 errors

4 = mostly correct; fewer than three errors total

3 = some major inconsistencies in referencing, or referencing not used frequently enough (e.g., perhaps just at ends of paragraphs); or two to three major usage, grammar, or punctuation errors (e.g., comma splices, incorrect capitalization, errors in verb tenses, pronoun agreement errors, "data" as singular instead of plural); ESL problems

2 = referencing is incorrect (e.g., may use "et al." instead of all names or for fewer than three authors); fails to reference assertions; mechanics are distracting, five or more errors (sloppy appearance or proofreading)

1 = totally unacceptable; many spelling and punctuation errors

A3) Style

- Avoids repetition & narrative; is concise; emphasizes key points & minimizes unimportant points
- Avoids poorly structured, long, run-on sentences
- Is easy to read; uses coherent devices to create "flow," e.g., topic sentences, "old to new" sentence construction, transitions
- Avoids vague, colloquial, imprecise vocabulary

5 = excellent in all these areas; would not know how to tell writer to improve

4 = good in all areas, but with occasional weak points (e.g., a wordy sentence or two, a poorly organized paragraph, one to two instances of repetition); or excellent in all areas except one

3 = problems in two of the four areas; readable but with some difficulty; choppy

2 = weak style but ideas are decipherable

1 = style interferes in major way with communication of ideas

B. HIGHER LEVEL THINKING/WRITING SKILLS

B1) Clarity & Quality of Content

- Includes clear, complete technical explanations
- Shows understanding of key concepts and assigned readings
- Has breadth; goes beyond assigned or minimal number of readings
- Appears to have depth; thinks critically; questions ideas; draws conclusions

5 = seems excellent to a general reader: clear, complete, logical

4 = seems generally clear and goes beyond minimum number of sources

3 = seems adequate but may have problems in two of the four areas

2 = less than adequate

1 = very confusing and shallow

B2) Synthesis

- Draws on literature to show understanding of the field by using citations and names of researchers
- Integrates ideas: makes comparisons, uses several citations together; makes a table to show similarities and differences
- Speculates on the meaning of similarities and differences

5 = excellent in all these areas
4 = excellent in one of these areas; or good in all but not outstanding; or uses citations but doesn't refer to names of researchers
3 = synthesizes occasionally but not uniformly throughout
2 = very little evidence of synthesis
1 = no comparisons

B3) Argumentation

- Provides an argument early on—thesis or main point
- Explains purpose (rationale) of paper/context for thesis
- Provides evidence/reasoning/authority for assertions
- Evaluates/questions material; raises issues, discusses controversies

5 = excellent in all these areas
4 = good in everything but does not state rationale for thesis or weaker on questioning material or discussing issues
3 = on the right track for an argument (starts as if to develop an argument), but not as well developed
2 = major problem in some area, such as no thesis, or assertions without support, or conclusion that is not substantiated by the evidence and reasoning
1 = very weak; assertions without evidence; logical fallacies

B4) Use of Charts and Tables

- Effectively uses multiple ways of presenting information, not just text

5 = figures/tables used appropriately to explain key points; each is labeled and numbered properly and explained with a caption and text; figures aid synthesis, argumentation, and explanations
4 = missing one key type of item, such as titles or numbers for figures or captions; but generally correct; still uses several graphs/charts to explain ideas; may have a graph or two that is not as appropriate or is in wrong spot
3 = makes an effort to use some tables and charts, but not handled consistently throughout; has at least one table or chart, well done; has two or more missing labels, numbers, etc., but figures help make the point
2 = has at least one table or chart, but not done well
1 = no visual representation, paper is plain text