# Bioengineers as Professional Communicators

## Assessing the Impact of the Cain Project on Undergraduate Student Performance in Professional Writing and Public Speaking at Rice

Technical Report to Rice University

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## Executive Summary

University programs in engineering are required by accreditation boards such as ABET to demonstrate that students graduate with "an ability to communicate effectively." However, universities have had difficulty with defining effective communication and with assessing whether students who complete their programs actually meet this requirement. In fact, universities rarely evaluate the effectiveness of domain-specific instruction in professional communication. Rice University was uniquely positioned to conduct such an assessment because it had a communication-in-the-disciplines program—the Cain Project—that for a decade focused on improving the communications skills of engineers and scientists. The research reported here assessed the impact of the Cain Project on the communication skills of undergraduate bioengineers at Rice.

This study examined the effectiveness of the Cain Project on student performance in three typical professional genres: technical reports, technical posters, and oral presentations. The central questions were: "Did students change from their sophomore to senior year, and if so, in what ways?" "Did students improve over successive years of the Cain Project?" "Did the Cain Project add value to students' education at Rice?" These questions were investigated by assessing the artifacts (technical reports, posters, and oral presentations) created by sophomore and senior teams from 2003–2008. Across the three genres, five key features of students' work were evaluated: (1) comprehensibility, (2) persuasiveness, (3) accessibility, (4) intercultural/interpersonal effectiveness, and (5) usability.

Results suggest the Cain Project did indeed add value to students' education at Rice for it helped young engineers develop their professional communication abilities in substantial ways. Sophomores made significant improvements over successive years in making their technical reports accessible to a reader. Sophomores also improved in their oral presentations, making them significantly more comprehensible, accessible, effective, and usable. Seniors performed significantly better than sophomores in all three genres and did especially well in 2008 on oral presentations. Generally speaking, sophomores focused more on proving they had mastered the subject matter rather than on engaging an audience. By senior year, however, students had shifted their rhetorical stance from "reporter of someone else's knowledge" to "creator of their own knowledge." By the time they were ready to graduate, students had learned to make typical problems in bioengineering clear and compelling for difficult audiences such as venture capitalists.

Overall, this assessment of student outcomes found that courses in bioengineering at Rice taught students to think like a domain expert while the Cain Project helped them to communicate like one—moving flexibly from making calculations to creating quantitative displays, from designing prototypes to marshalling arguments, from acquiring disciplinary knowledge to sharing it. Students mastered a number of the typical genres of their field, but also acquired a deeper understanding of how their field communicates its knowledge, intellectual products, and values.

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## NOTE FROM AUTHORS

This report originally included appendices A–L (see the List of Appendices on page iv). The IRB that reviewed this report believed appendices C–L were potentially compromising because they reported the raw data of student teams. At their request, we have omitted appendices C–L and include in this report only appendices A and B.

We have *not* removed references to appendices C–L in the table of contents or the text because we think readers will better understand how the data were analyzed by reading the original text even without the raw data. We hope that the charts and graphs displayed throughout the text tell the story of this assessment without the need for the detailed appendices.

# INTRODUCTION

University programs in engineering are required by accreditation boards such as ABET to demonstrate that students graduate with "an ability to communicate effectively." However, universities have had difficulty both with defining effective communication and assessing whether students who complete their programs actually meet this requirement. Further, universities rarely assess the effectiveness of domain-specific instruction in professional communication. Rice University was uniquely positioned to conduct such an assessment because it had a communication-in-the-disciplines program—the Cain Project—that for a decade focused on improving the communications skills of engineers and scientists. The research reported here assessed the impact of the Cain Project on the communication skills of bioengineers at Rice.

## Background: The Cain Project at Rice

Between 1999 and 2008, the Cain Project played a central role in preparing students at Rice to become better communicators as they developed expertise in engineering and science. The Cain Project was carried out through activities such as seminars, in-class presentations, mentoring, coaching, team teaching, and materials development. The philosophy underlying this communication-in-the-disciplines program was to raise the bar for excellence in professional communication at Rice by supporting its faculty and students across-the-curriculum—in large lecture classes, small seminars, design courses, laboratory courses, graduate seminars, and in thesis preparation groups.

### Development of Heuristics for Communication

In collaboration with Rice faculty, Cain Project staff developed practical heuristics for teaching and evaluating common professional genres such as technical reports, poster presentations, technical memos, and oral presentations. These heuristics were designed to allow faculty to place greater emphasis on communication while at the same time helping students to solve scientific and technical problems in their area of study. In this way, the Cain Project aimed to help Rice faculty meet their course objectives and overall program goals.

Over the decade of the Cain Project, faculty and communications-in-the-disciplines staff worked together to integrate professional communication instruction into required undergraduate courses. Their goal was to prepare students to communicate as professional bioengineers—able to construct cogent technical arguments, make complex analyses clear, and marshal quantitative evidence for a wide range of technical and nontechnical audiences (such as bosses, clients, technical peers, and funding agencies).

### Implementation of Iterative Design Procedures for Communication

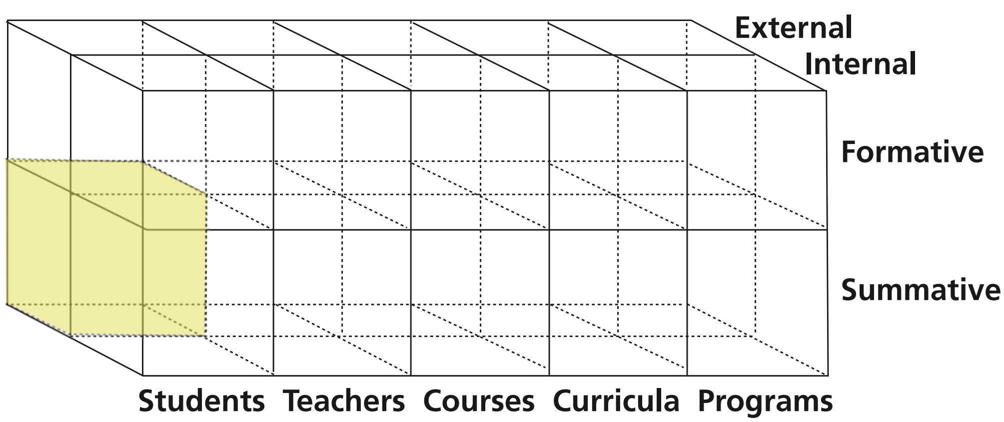
In addition to initiatives led by the Cain Project, bioengineering faculty made substantial curriculum changes between 2005 and 2006 when they moved from lecture-based approaches to teaching to more student-centered approaches. Faculty revised their courses and refocused their assignments. For example, teachers shifted from "traditional lab reports" to "problem-driven lab reports." This change called on students to move from "dumping" their knowledge in list-like fashion to organizing their lab reports around ill-defined problems that they had explored in interdisciplinary teams.

As important, faculty adopted an iterative design model for creating professional communications. Instead of simply asking students to turn in a technical report at the end of semester, students were required to produce multiple drafts en route to a final report. Teachers and Cain project staff made extensive comments on these drafts, suggesting strategies to students for making their communications more comprehensible, accessible, usable, and rhetorically sensitive. Teachers' emphasis on iterative design was implemented across the range of communications students produced—from technical reports to oral presentations. Between 2006 and 2008, students routinely had to produce multiple drafts across all genres. As ideas from the Cain project were integrated into the curriculum, students were increasingly challenged to consolidate their problem solving in bioengineering through writing, visualization, and oral presentation.

## **Goals for Study:** Assessing Student Improvement

Although faculty would likely attest that the Cain Project had a positive influence on students' skills in professional communication, there had not been an empirical evaluation of student outcomes until this study. The aim of this research was to identify whether the Cain project actually had an impact on student performance in professional communication. Figure 1 provides a descriptive framework of educational assessment, showing the context of this assessment.

**Figure 1.** A framework for assessment, specifying the context of the study.




The framework specifies three dimensions of educational assessments: (1) *when* the assessment is conducted (formative or summative); (2) *who* conducts the assessment (external or internal evaluators); and (3) *who or what* is being assessed (students, teachers, courses, curricula, or programs) (Hayes & Schriver, 1999; Schriver, 2008). As Figure 1 shows, this study was a summative external assessment of student performance that evaluated students' work after their participation in the Cain Project. Moreover, it was a direct assessment of students' work in professional communication (as opposed to an indirect, standardized test). It evaluated authentic classroom-based samples of students' oral and written communications (Pagano et al. 2008; Yancey, 1999).

### Hypotheses and Research Questions

The hypotheses for this outcomes assessment of student performance were straightforward.

***Hypothesis 1.*** If the Cain Project was successful in meeting its goals in improving students' communication skills, we would expect to see that senior bioengineers would be better at professional communication than students in their sophomore or junior year.

> Research question 1. Did students improve in their professional communication skills from their sophomore to senior year? If so, in what ways and on which genres?

***Hypothesis 2***. As the Cain Project matured and communication became more deeply embedded in the curriculum, we would expect the impact of the Cain Project to increase. There are two ways this could happen. First, it could be that both sophomores and seniors improved over time. Second, it could be that the impact was primarily on seniors because the Cain project had a cumulative effect from sophomore to senior year. The second alternative seemed more plausible than the first because the Cain Project had relatively little opportunity to influence students early in their college career. These alternative explanations suggested two research questions:

> Research question 2a. Did both sophomores and seniors improve their professional communication skills over successive years with the Cain Project?

> Research question 2b. Did the advantage of seniors over sophomores increase in successive years of the Cain Project? That is, did the added value of education in professional communication increase over time?

To investigate these questions, KSA assessed the output of student teams enrolled in required entry-level and exit-level undergraduate bioengineering courses. We evaluated the final drafts of technical reports, scientific posters, and videotapes of oral presentations. The study assessed changes in students' abilities by comparing the quality of their communication artifacts over time.

## METHODS: QUASI-EXPERIMENTAL AND DESCRIPTIVE

### Limitations of Study Design

KSA's approach was constrained by the nature of the available data. Due to its mission, the Cain Project necessarily focused on improving instruction rather than on collecting data with an outcomes assessment in mind. Between 2001 and 2008, the Cain Project collected a range of artifacts produced by students who took communication-intensive courses in bioengineering, artifacts ranging from technical memos to 70-page design reports. Bioengineering faculty and Cain Project staff drew from this extensive corpus for the materials for this study and recommended courses from which to sample sophomore, junior, and senior work.

Student performances from three courses were recommended for study: sophomores from the fundamentals course, BIOE 252; juniors from the tissue lab, BIOE 342; and seniors from the capstone course, BIOE 451/2. Although students' work had been saved for each of these courses, students who provided artifacts for the sophomore course were not necessarily the same students who provided artifacts for the senior course.

Consequently, the data for this assessment did not lend themselves to within-subject comparisons of individual students carrying out similar tasks, early and late in their program at Rice. In addition, the data did not allow for controlled comparisons of students who took courses influenced by the Cain project with students enrolled in courses not influenced by the Cain project. Ideally to make the strongest case for change in student performance we would have had a control group that did not receive the Cain Project instruction. Because an experimental design was not possible, we took a quasi-experimental approach using the convenience sample made available to us.

### Strengths of Study Design

Even though the data were not collected with an assessment in mind, they still provide a window on the quality of student performance in professional communication. An important strength of this research is that the data offer more than a single snapshot of a single genre in a single course in a single year. Instead, this research investigated three student cohorts taking the same entry-level and exit-level courses between 2001 and 2008. For each of the three student cohorts, samples from each of the three genres were available for study. This allowed for comparison of students' entry-level and exit-level skills as well as for comparison of student performance on the three genres over time.

### Participants and Sample

Bioengineering faculty nominated the work of 70 student teams to be part of the study, providing KSA with a convenience sample of students who took courses between 2001 and 2008. As mentioned above, students' work was drawn from three courses:

1. Technical reports and oral presentations from the sophomore fundamentals course, BIOE 252;
2. Scientific posters from the junior-level tissue lab course, BIOE 342; and
3. Technical reports, posters, and oral presentations from the senior capstone course, BIOE 451/2.

## Study Design

This research employed a quasi-experimental pretest-posttest design. In particular, the work of sophomores and juniors formed the pretest and the work of seniors constituted the posttest. To allow for comparisons of students as they progressed through the bioengineering curriculum, the data were organized as three cohorts between 2003 and 2008. Cohorts were defined by students' graduating year rather than by the year the data were collected. This organization allowed us to track the impact of the Cain project on student performance on each genre over a six-year period.

For each cohort, roughly 24 communication artifacts were assessed: 12 created by sophomores/juniors and 12 by seniors: 4 technical reports, 4 oral presentations, and 4 scientific posters. In total, 34 communication artifacts from sophomores/juniors were judged as representing entry-level skills while 36 artifacts from senior teams were coded as representing exit-level skills (see Figure 2).

| **PRETEST (Sophomores/Juniors)** | | | | **POSTTEST (Seniors)** | | | |
|---|---|---|---|---|---|---|---|
| **Cohort & Year of Graduation** | **Year Data Collected** | **Genres Assessed** | **N** | **Cohort & Year of Graduation** | **Year Data Collected** | **Genres Assessed** | **N** |
| **Cohort 1** | | | | **Cohort 1** | | | |
| Class of 03 | 2001 | Technical Reports[1] | n = 2 | Class of 03 | 2003 | Technical Reports | n = 4 |
| Class of 05 | 2004 | Posters[2] | n = 4 | Class of 05 | 2004/5 | Posters | n = 4 |
| Class of 03 | 2001 | Oral Presentations[1] | n = 4 | Class of 03 | 2003 | Oral Presentations | n = 4 |
| | | | **n = 10** | | | | **n = 12** |
| **Cohort 2** | | | | **Cohort 2** | | | |
| Class of 05/6 | 2003 | Technical Reports[1] | n = 4 | Class of 05/6 | 2006 | Technical Reports | n = 4 |
| Class of 06/7 | 2006 | Posters[2] | n = 4 | Class of 06/7 | 2005/6 | Posters | n = 4 |
| Class of 05/6 | 2003 | Oral Presentations[1] | n = 4 | Class of 05/6 | 2006 | Oral Presentations | n = 4 |
| | | | **n = 12** | | | | **n = 12** |
| **Cohort 3** | | | | **Cohort 3** | | | |
| Class of 08 | 2006 | Technical Reports[1] | n = 4 | Class of 08 | 2008 | Technical Reports | n = 4 |
| Class of 08 | 2007 | Posters[2] | n = 4 | Class of 08 | 2007/8 | Posters | n = 4 |
| Class of 08 | 2006 | Oral Presentations[1] | n = 4 | Class of 08 | 2008 | Oral Presentations | n = 4 |
| | | | **n = 12** | | | | **n = 12** |
| | | | **n = 34** | | | | **n = 36** |

[1] Participants were sophomores
[2] Participants were juniors

**Figure 2.** Study design: Assessing bioengineers as professional communicators.

### Coding the Data

To assess student performance, a coding rubric was developed to capture the distinctive characteristics of well-designed professional communications. Three sources guided the design of the rubric:

1. Bioengineering teachers' instructional goals and grading criteria for effective technical reports, posters, and oral presentations
2. Assessment heuristics for engineering design reports and oral presentations developed by the Cain Project's communication-in-the-discipline's staff
3. The consolidated findings of writing research and best practices in document design, technical writing, and engineering communication (Abelson, 1995; Burnett; 1994; Gosling, 1999; Hart, 2008; Nicol & Pexman, 2003; Penrose, 2004; Schriver, 1997; Tufte, 1983)

An additional goal in generating the coding rubric was to identify characteristics of effective professional communication that cut across all three technical genres under study. In this way, a single rubric could be employed for assessing students' work in each of the three genres.

Taken together, the three sources suggested five key variables that index well-designed professional communications (presented in Figure 3).

| Coding for Effectiveness in Professional Communication: 5 Key Variables | |
|---|---|
| **1 Comprehensibility** | Will readers/listeners understand the visual/verbal message? Does it adhere to standards for clear writing/speaking? |
| **2 Persuasiveness** | Will readers/listeners find the argument compelling? Is there a credible articulation of the problem and its solution? |
| **3 Accessibility** | Will readers readily grasp the organization and find what they want quickly? Can listeners anticipate what is coming next? |
| **4 Intercultural/ Interpersonal Effectiveness** | Will readers/listeners come away with an impression that the content is sensitive to their viewpoint and information needs? |
| **5 Usability** | Is the communication designed in ways that enable readers/listeners to use the content as they see fit? |

**Figure 3.** Five key variables of professional communication assessed in coding student performance.

To help coders make more consistent and reliable judgments, the 5 variables were defined by a number of sub-variables. In total, the rubric was elaborated with 15 sub-variables important for effective communication in bioengineering (see Figure 4 on the next page). For example, "comprehensibility" was specified to include: (a) use of standard conventions for professional writing/speaking; (b) use of clear visual conventions for quantitative displays, charts, and photographs; (c) effective use of genre/disciplinary conventions; and (d) effective presentation of technical content. Each artifact was assessed for the 5 key variables, the 15 sub-variables (see Appendix A for the rubric), and the grand mean overall (for a total of 21 measures).

To remind the coders of the meanings of the sub-variables, each was detailed in a more exhaustive rubric (see Appendix B). The assessment rubric (Appendix A) was employed to score each artifact; the more detailed rubric (Appendix B) was used to guide coders in interpreting the variables.

### Calibrating the Coding

Two coders judged the set of 70 student artifacts. The first coder—an expert in writing research and information design—was for a decade a professor of rhetoric and professional communication at Carnegie Mellon, a position that required evaluating the writing, design, and public speaking of students in science, technology, business, and the humanities. The second coder—a current professor of cognitive psychology at Carnegie Mellon and a pioneer in research on writing—has designed many assessments of the impact of instruction on learning in the humanities and the sciences.

| Coding for Effectiveness in Professional Communication: 5 Key Variables and 15 Sub-variables | |
|---|---|
| **1 Comprehensibility** | Will readers/listeners understand the visual/verbal message? Does it adhere to standards for clear writing/speaking?<br><br>1.1 Use of standard conventions for professional writing/speaking<br>1.2 Use of conventions for clear visual displays, charts, photographs<br>1.3 Adherence to conventions of genre/discipline<br>1.4 Adherence to standards for marshalling technical content |
| **2 Persuasiveness** | Will readers/listeners find the argument compelling? Is there a credible articulation of the problem and its solution?<br><br>2.1 Cogent discussion of options/possible solutions<br>2.2 Credible articulation of technical argument/approach<br>2.3 Professional application of methods and computations<br>2.4 Demonstrated awareness of strengths, limitations, implications |
| **3 Accessibility** | Will readers readily grasp the organization and find what they want quickly? Can listeners anticipate what is coming next?<br><br>3.1 Document design is clear and purposeful<br>3.2 Structure reveals hierarchy of content<br>3.3 Summaries and previews integrate and interpret content |
| **4 Intercultural/ Interpersonal Effectiveness** | Will readers/listeners come away with an impression that the content is sensitive to their viewpoint and information needs?<br><br>4.1 Content shows sensitivity to the audience's expectations<br>4.2 Design choices are adapted to the culture and situation |
| **5 Usability** | Is the communication designed in ways that enable readers/listeners to use the content as they see fit?<br><br>5.1 Match between content and audience's purposes<br>5.2 Explanations make evident ways to use or assess content |

**Figure 4**. Five key variables and 15 sub-variables assessed in coding student performance.

To calibrate their judgments using the assessment rubric, the coders rated four student samples from each genre together. For each of the three genres, two student samples were chosen randomly from the sophomore/junior cohorts and two from the senior cohorts. Coders then read or listened to a given artifact and discussed the visual, verbal, or oral moves that were indicators of the 5 key variables for that genre. Next, the coders judged the four artifacts for the 15 sub-variables, rating each with a score from 1 (poor) to 5 (excellent) (see Appendix A). After making their judgments, coders discussed why they rated the artifacts as they did.

This procedure allowed coders to acquire a sense of how each interpreted the variables and prompted them to make explicit the evidence that led them to particular scores. As coders adjudicated their decisions, they acquired a model of how to evaluate that genre. After the calibration session, the coders assessed the remaining 20+ samples from the genre by making their judgments independently on randomly ordered artifacts.

Once the evaluations for a given genre were complete, coders went on to the next genre and employed the same calibration procedure. One exception to this norming protocol was made in judgments for the oral presentations. Samples of students' oral presentations had been videotaped in the classroom and in half of the samples, the quality of the audio was uneven, which made it difficult to hear what students were saying. For these 12 cases, coders rated the presentations together so they could help each other understand what students said. Inter-rater reliability was based on 12 samples raters coded independently.

### Inter-rater Reliability

Overall, the two coders evaluated the 70 artifacts by rating each for the 15 sub-variables, making 1080 judgments. Inter-rater reliability was calculated on judgments for each genre that had been made independently (see Appendix C). For technical reports, the inter-rater correlation between judges was .76, for posters .86, and for oral presentations .89. Averaged over the three genres, the inter-rater reliability was .84 as measured by Pearson Product-Moment correlations. A reliability coefficient of .7 or above is generally considered acceptable, while coefficients above .8 are considered outstanding (Landis & Koch, 1977).

## Data Analysis

The data were analyzed quantitatively and qualitatively. Quantitative analyses consisted of analyses of variance and Mann-Whitney U tests. These analyses were preceded by a weighted scoring procedure, described next. The qualitative analysis also involved consolidating comments written by the raters during their assessment of each artifact and integrating their summary comments of student performance on each genre.

### Weighted Scoring

Discussion with bioengineering faculty indicated that they placed more significance on the first three key variables, *comprehensibility, persuasiveness,* and *accessibility* than the latter two, *intercultural/interpersonal effectiveness,* and *usability.* To reflect these pedagogical emphases, students' total scores for the grand mean were adjusted by assigning a weight of 2 to the first three variables and 1 to the last two.

### Approach and Rationale

For each of the three genres, two-way analyses of variance were conducted on the following data: (1) the grand means (using the weighted scores described above), (2) the 5 key variables, and (3) the 15 sub-variables. In all cases, the dependent variable was the rating of student performance from 1 (poor) to 5 (excellent). The independent variables were (1) cohort (2003, 2006, and 2008) and (2) pretest–posttest, corresponding to sophomore/junior or senior year. For each ANOVA, a Levene test for homogeneity of variance was conducted. When a main effect or an interaction was significant (the alpha level was set at .05) or marginally significant ($p < .10$), follow-on pair-wise comparisons were deemed appropriate. Because many of the Levene tests revealed a lack of homogeneity in the variance, we chose to employ the Mann-Whitney U test to carry out the follow-on paired comparisons. Unlike t-tests, Mann Whitney's are not influenced by the lack of homogeneity.

The follow-on Mann-Whitney analyses made nine comparisons between student groups for each dependent variable that was significant by analysis of variance: sophomores versus seniors for each of the three cohorts (e.g., 2003, 2005, 2008) and 2003-2005, 2003-2008, and 2005-2008 for sophomores and seniors. Thus, to determine if students improved from sophomore to senior year, sophomores were compared to seniors in 2003, 2006, and 2008. Similarly, to determine if students improved over successive years of the Cain Project, sophomores in each cohort were compared with sophomores in the other cohorts (2003-2005, 2003-2008, and 2005-2008) and seniors in each cohort were compared to seniors in the other cohorts (2003-2005, 2003-2008, and 2005-2008).

## RESULTS

This assessment investigated the question, "What impact did the Cain Project have on undergraduate performance in professional communication at Rice?" We begin with a general characterization of the data, providing a set of charts that depict the major trends in sophomore/junior versus senior performance. After a depiction of the big picture, we move to details about bioengineers' performance on the three genres: technical reports, scientific posters, and oral presentations. In particular, we report results of the analyses of variance and the Mann-Whitney U tests. Within the discussion of each genre, we characterize students' strengths and weaknesses as professional communicators.

### **The Big Picture:** Performance Over Three Genres

Figure 5 provides a summary of bioengineers' overall performance, collapsed over the three genres. As shown, students who took part in the Cain Project did indeed improve from their sophomore to senior year. Seniors performed better than sophomores, beginning in 2005/6 and made their most dramatic gains in 2008. Sophomores, who were just starting out as bioengineers, performed at roughly the same level over the 6-year period. (Limitations in the available sample prevent us from knowing how sophomores performed who were not part of the Cain Project.)

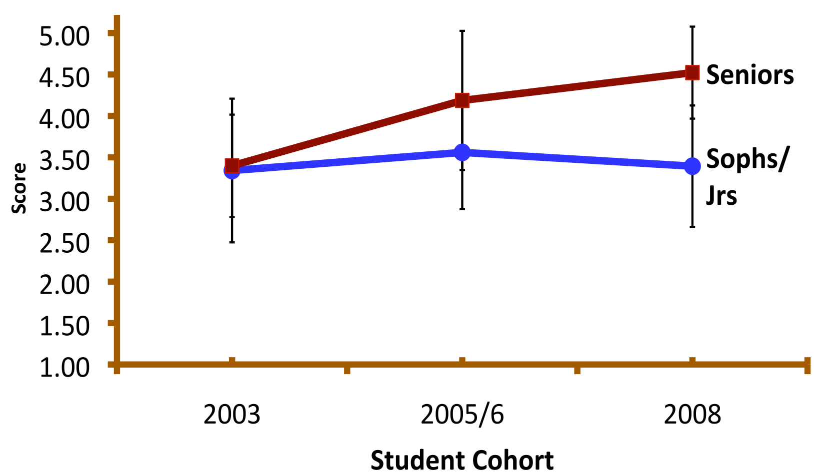



**Figure 5.** Impact of the Cain Project: Bioengineers' overall performance as professional communicators across three genres and three cohorts.

Figures 6, 7, and 8 provide an overview of students' performance on the three genres: technical reports, scientific posters, and oral presentations.

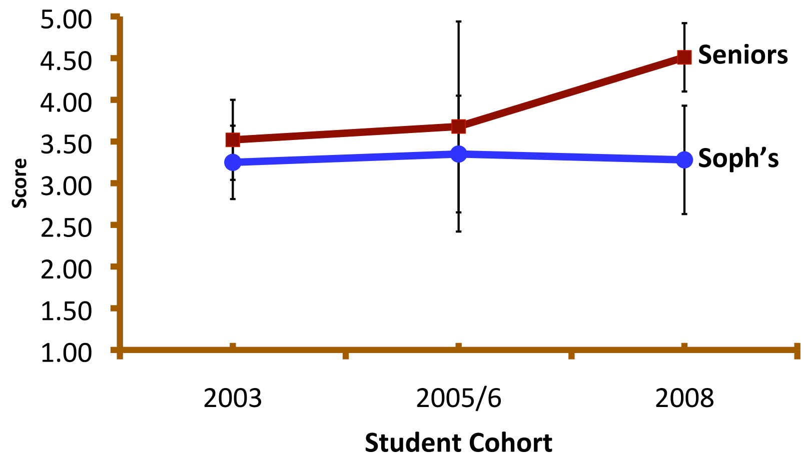



**Figure 6.** Bioengineers' overall performance on technical reports.

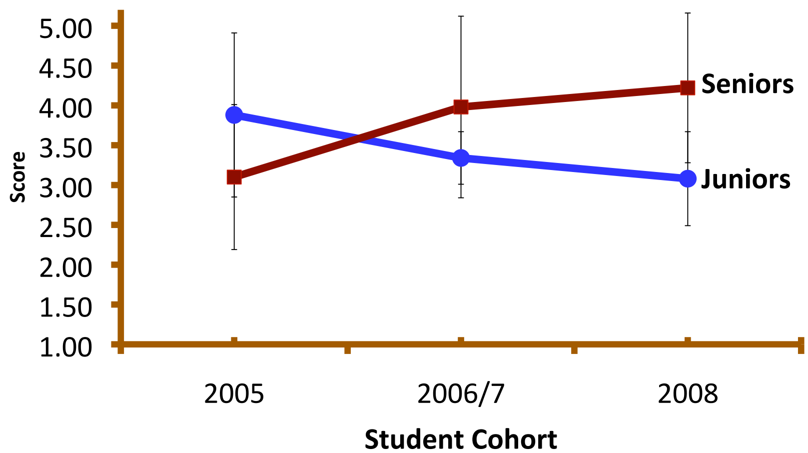



**Figure 7.** Bioengineers' overall performance on posters.

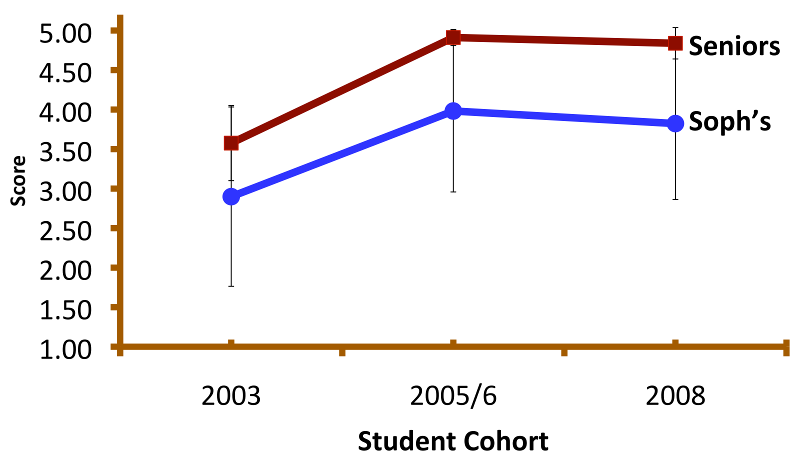



**Figure 8.** Bioengineers' overall performance on oral presentations.

The trends depicted in Figures 6–8 give a general picture of the performance of (1) sophomores/juniors over time, (2) seniors over time, and (3) sophomores/juniors versus seniors for the three cohorts. As shown, sophomores performed at relatively stable levels for the three genres, with no significant differences overall across the cohorts. Seniors improved over time on each of the genres, performing best in 2008 on technical reports ($M = 4.51$, $SD = .41$) and oral presentations ($M = 4.84$; $SD = .20$). Seniors also performed better than sophomores/juniors on each genre, particularly as the communication-within-the-disciplines became more integrated into the curriculum between 2005 and 2008.

How students performed in each of the three genres is detailed next, with a focus on student achievement on the five key variables and the 15 sub-variables. These data suggest the Cain Project had the most impact on seniors, with significant improvements on many key features of professional communication. The data also indicate that sophomores' performance on the three genres did not change much overall, but they did make significant improvements in the design of technical reports and oral presentations. We will elaborate these general points next by discussing technical reports first, followed by posters, and then oral presentations.

## GENRE 1: BIOENGINEERS' PERFORMANCE ON TECHNICAL REPORTS

The raw scores for students' performance on technical reports are summarized as a 5-page table in Appendix D. This summary shows students' scores for pretest and posttest across the three student cohorts for each variable. Appendix D also shows the mean scores for each cohort, the standard deviations, and overall means for each of the 15 sub-variables that comprise the 5 key variables under evaluation.

Drawing on this data set, Appendix E consolidates the 15 sub-variables as a one-page snapshot of how students did on each of the 5 key variables: (1) comprehensibility, (2) persuasiveness, (3) accessibility, (4) intercultural/interpersonal effectiveness, and (5) usability. In addition, Appendix E also presents the weighted mean scores of the 5 key variables from pretest to posttest for each cohort. As mentioned earlier, students' scores were weighted to reflect teachers' pedagogical emphases, with variables #1–3 assigned a weight of 2, and variables #4–5 a weight of 1.

Below we present the main findings for our assessment of technical reports. We begin with an overview of how students performed across the genre as a whole. We then provide the findings for the 5 key variables and their sub-variables.

### Results for Technical Reports

As mentioned above, two-way ANOVAs were conducted for 21 measures: (1) the grand mean, (2) the 5 key variables, and (3) the 15 sub-variables. Student score was the dependent variable, while pretest–posttest and cohort were the independent variables. Again, both significant and marginally significant results were explored with Mann-Whitney U follow-on tests.

The results for two-way analyses of variance for technical reports are presented in Table 1. The results of the Levene tests for the ANOVAs are shown in the right-hand column and the variables on which Mann-Whitney tests were conducted are checked.

**Table 1.** Results for technical reports: Two-way analyses of variance.

| Results of ANOVAs for Technical Reports[1] | | | | | |
|---|---|---|---|---|---|
| N = 22 10 Pretest; 12 Posttest | **Pretest-Posttest[2]** | **Cohort[3]** | **Interaction** | **MW[4]** | **Levene Test[5]** |
| **Grand Mean for 5 Key Variables** | | | | | |
| Weighted Means[6] | 0.082 | NS | NS | ✓ | NS |
| **1. Comprehensibility Overall** | NS | NS | NS | | 0.02 |
| 1.1 Writing Conventions | NS | NS | NS | | NS |
| 1.2 Visual Conventions | **0.005*** | NS | **0.043** | ✓ | 0.01 |
| 1.3 Genre Conventions | NS | NS | NS | | 0.001 |
| 1.4 Technical Content | NS | NS | NS | | NS |
| **2. Persuasiveness Overall** | NS | NS | NS | | NS |
| 2.1 Options/Solutions | NS | NS | NS | | NS |
| 2.2 Technical Approach | NS | NS | 0.089 | ✓ | NS |
| 2.3 Methods/Computations | NS | NS | NS | | NS |
| 2.4 Strengths, Limits, Implications | NS | NS | NS | | NS |
| **3. Accessibility Overall** | **0.008** | **0.048** | NS | ✓ | 0.039 |
| 3.1 Document Design | **0.002** | **0.019** | NS | ✓ | NS |
| 3.2 Structure & Hierarchy | **0.008** | NS | NS | ✓ | 0.005 |
| 3.3 Summaries & Previews | NS | 0.093 | NS | ✓ | 0.032 |
| **4. Intercultural/Interpersonal Overall** | NS | NS | NS | | NS |
| 4.1 Sensitivity to Audience | 0.065 | NS | NS | ✓ | NS |
| 4.2 Adapted to Culture/Situation | NS | NS | NS | | NS |
| **5. Usability Overall** | NS | NS | NS | | NS |
| 5.1 Content Fits Purpose | NS | NS | NS | | NS |
| 5.2 Explanations Useful | NS | NS | NS | | NS |

* Numbers in **boldface** are significant at .05 level or greater; others are marginally significant.

[1] Two-way ANOVAs were conducted for each variable. Student score (1-5) was the dependent variable. The independent variables were the following: (1) cohort (1, 2, or 3—corresponding to graduation year) and (2) pretest-posttest (sophomore or senior).

[2] All sophomores were coded as pretest participants; all seniors as posttest.

[3] There were 3 cohorts: (1) Class of 2003, (2) Class of 2005/6, (3) Class of 2008.

[4] Items checked indicate that follow-on Mann-Whitney U (MW) analyses were conducted for the following: (1) sophomores vs seniors, (2) sophomores only, and (3) seniors only for each of the three 3 cohorts: (1) Class of 2003, (2) Class of 2005/6, (3) Class of 2008.

[5] Levene's Test evaluates the null hypothesis that the error variance of the dependent variable is equal across groups. A significant Levene suggests non-homogenous variance.

[6] Weights were as follows: (1) comprehensibility = 2; (2) persuasiveness = 2; (3) accessibility = 2; (4) intercultural = 1; (5) usability = 1.

A summary of the Mann-Whitney U tests for technical reports is presented in Appendix F. Because these results are somewhat lengthy, as an aid the reader we also present the analyses in the body of the report as we discuss each variable.

### Overall Performance for Technical Reports

Table 1 shows that analysis of the grand mean for the 5 key variables produced a marginally significant main effect for pretest-posttest ($F = 3.445$; $df = 1,16$; $p = .082$). This finding suggested that students' performance differences might be significant and should be followed on with non-parametric analyses. Mann-Whitney U tests (shown in Table 2) indicated that seniors created better technical reports than did sophomores in 2008 and that seniors improved significantly between 2003 and 2008. Students' overall performance on technical reports is graphed in Figure 6 (shown earlier on page 10).

**Table 2.** Mann-Whitney U results for technical reports over 5 key variables: Weighted grand mean.

| Mann-Whitney U Analyses for Technical Reports: Weighted Grand Mean for 5 Key Variables | | | |
|---|---|---|---|
| **Group** | **Cohort Year** | **Mann-Whitney[1]** | **MW U Stat[2]** |
| **Sophomores vs Seniors** | 2003 | NS | |
| | 2005/6 | NS | |
| | 2008 | 0.022 | 0 |
| **Sophomores (only)** | 2003-2005 | NS | |
| | 2003-2008 | NS | |
| | 2005-2008 | NS | |
| **Seniors (only)** | 2003-2005 | NS | |
| | 2003-2008 | 0.022 | 1.0 |
| | 2005-2008 | NS | |

[1] One-tailed p-value (significance level set at .05).
[2] The Mann-Whitney U statistic.

Mann-Whitney analyses were conducted for the sub-variables that the ANOVAs found to be significant or marginally significant. As Table 1 shows, over the five key variables significant results were obtained in the *comprehensibility* (variable #1) and *accessibility* (variable #3) of technical reports.

#### Key Variable: Comprehensibility of Technical Reports

There were no overall significant effects for the comprehensibility of technical reports. However, of the four sub-variables of comprehensibility—(1) writing conventions, (2) visual conventions, (3) genre conventions, and (4) technical content—there was a significant effect for use of effective *visual conventions* (item 1.2).

***Visual conventions.*** When a technical report makes use of effective visual conventions, the charts, graphs, visual displays, or photos are carefully designed to support the text. Visual conventions include explanatory captions and legends that put the main points into focus.

A main effect was found for use of visual conventions in the design of technical reports between pretest and posttest ($F = 10.391$; $df = 1,16$; $p = .005$). There was also a significant interaction between pretest–posttest and cohort ($F = 3.841$, $df = 2,16$; $p = .043$). These results are summarized in Table 1, item 1.2. Follow-on Mann-Whitney U tests (shown in Table 3) indicated that seniors performed significantly better than sophomores in employing effective visual conventions in 2005/6 and in 2008.

**Table 3.** Mann-Whitney U results for comprehensibility of technical reports: Visual conventions.

| Mann-Whitney U Analyses for Technical Reports: Visual Conventions | | | |
|---|---|---|---|
| **Group** | **Cohort Year** | **Mann-Whitney[1]** | **MW U Stat[2]** |
| **Sophomores vs Seniors** | 2003 | NS | |
| | 2005/6 | 0.054 | 2.50 |
| | 2008 | 0.009 | 0 |
| **Sophomores (only)** | 2003-2005 | NS | |
| | 2003-2008 | NS | |
| | 2005-2008 | NS | |
| **Seniors (only)** | 2003-2005 | NS | |
| | 2003-2008 | 0.009 | 0.0 |
| | 2005-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

In addition, seniors made significant improvements between 2003 and 2008. These trends are depicted in Figure 9.

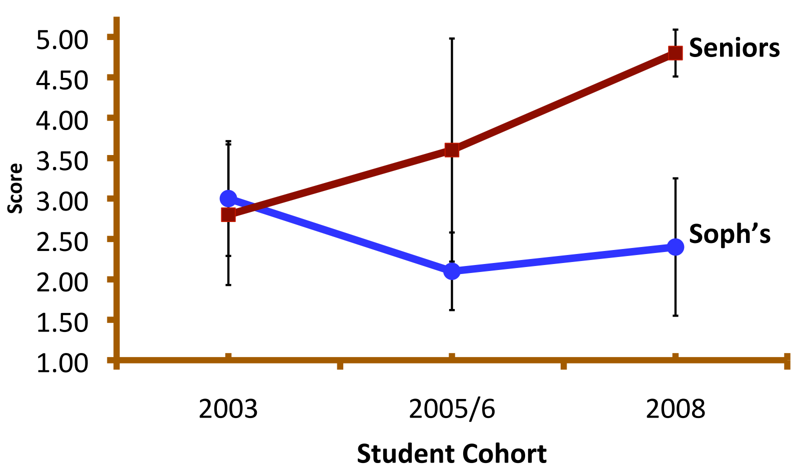



**Figure 9.** Designing comprehensible technical reports: Student performance on visual conventions.

## **Key Variable:** Persuasiveness of Technical Reports

KSA assessed "persuasiveness" by asking how well the reports marshaled a technical argument. In other words, was the argument credible and compelling? The analysis showed no overall impact for persuasiveness in the design of technical reports for pretest–posttest or cohort. However, there was an interaction for *technical approach* (item 2.2).

***Technical approach.*** When the technical approach is persuasive, the authors explicitly state the assumptions and rationale for what was done and how it was done.

Results of an ANOVA summarized in Table 1, item 2.2, show a marginally significant interaction ($F = 2.821$; $df = 2,16$; $p = .089$), suggesting that seniors' technical approach improved more over time than did sophomores. Follow-on Mann-Whitney tests (see Table 4) indicated that seniors' technical approach was superior to sophomores in 2008. In addition, seniors made significant improvements between 2003 and 2008 (see Figure 10).

**Table 4.** Mann-Whitney U results for persuasiveness of technical reports: Technical approach.

**Mann-Whitney U Analyses for Technical Reports: Technical Approach**

| Group | Cohort Year | Mann-Whitney[1] | MW U Stat[2] |
|---|---|---|---|
| Sophomores vs Seniors | 2003 | NS | |
| | 2005/6 | NS | |
| | 2008 | 0.032 | 2 |
| Sophomores (only) | 2003-2005 | NS | |
| | 2003-2008 | NS | |
| | 2005-2008 | NS | |
| Seniors (only) | 2003-2005 | NS | |
| | 2003-2008 | 0.019 | 1.0 |
| | 2005-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

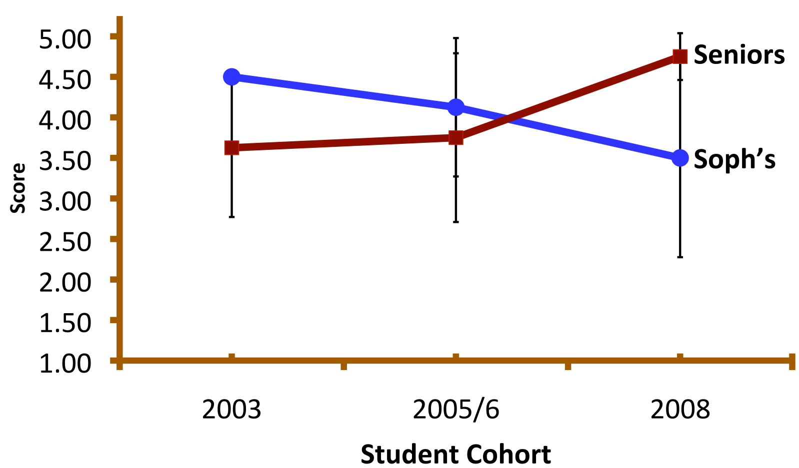



**Figure 10.** Designing persuasive technical reports: Technical approach.

***Strengths, limitations and implications.*** Readers typically find the argument of a technical report to be compelling when the authors demonstrate an awareness of the strengths, limitations, and implications of their approach, strategy, and solutions.

An ANOVA showed no significant results for this characteristic of persuasiveness. However, coders did note that both sophomores and seniors did consistently well on this aspect of their technical reports (see Figure 11). Sophomores had an average score of 4.13 while seniors' mean score was 4.46 (see Appendix D for details).

For both sophomores and seniors, "strengths, limitations, and implications" was the best score of the four coded for "persuasiveness." In fact, it received the highest mean score for both groups over all of the 15 sub-variables for technical reports.

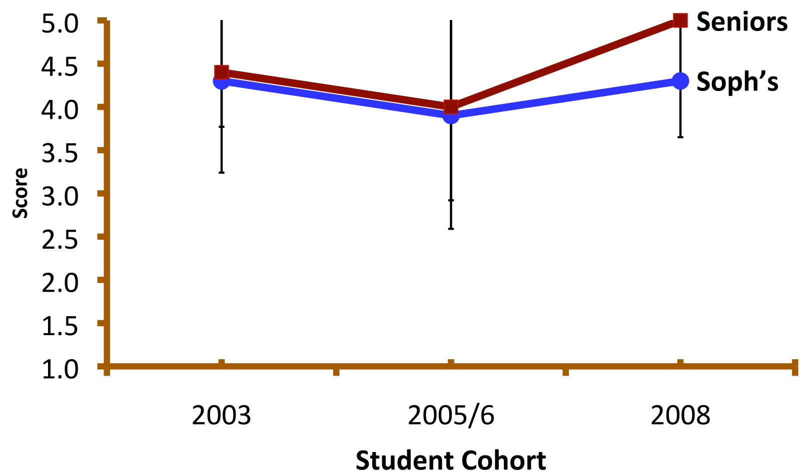



**Figure 11**. Designing persuasive technical reports: Strengths, limitations and implications.

**Key Variable:** Accessibility of Technical Reports

***Grand mean for accessibility overall.*** When a technical report has been designed to promote accessibility overall, its structural features ease the burden on readers to obtain a sense of the big picture. Accessible technical reports also facilitate navigation, search, and retrieval.

Analyses were conducted to determine whether students' technical reports improved in their overall accessibility—that is, across the sub-variables of *document design, structure and hierarchy,* and *summaries and previews.* A two-way ANOVA (presented earlier in Table 1, item 3, page 12) showed a significant effect for *accessibility overall* for pretest–posttest ($F$ = 9.236; $df$ = 1,16; $p$ = .008) and for cohort ($F$ = 3.697; $df$ = 2,16; $p$ = .048). Results of follow-on Mann-Whitney U tests (shown in Table 5) indicate that in the 2008 cohort, seniors' technical reports were more accessible than those produced by sophomores.

As Table 5 shows, seniors also improved significantly between 2003 and 2008. Seniors in 2003 had a mean score of 3.21 ($SD$ = .77), while seniors in 2008 improved their mean to 4.58 ($SD$ = .22). These trends are displayed in Figure 12.

**Table 5.** Mann-Whitney U results for overall accessibility of technical reports.

**Mann-Whitney U Analyses for Technical Reports: Accessibility Overall**

| Group | Cohort Year | Mann-Whitney[1] | MW U Stat[2] |
|---|---|---|---|
| Sophomores vs Seniors | 2003 | NS | |
| | 2005/6 | NS | |
| | 2008 | 0.011 | 0 |
| Sophomores (only) | 2003-2005 | NS | |
| | 2003-2008 | NS | |
| | 2005-2008 | NS | |
| Seniors (only) | 2003-2005 | NS | |
| | 2003-2008 | 0.011 | 0.0 |
| | 2005-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

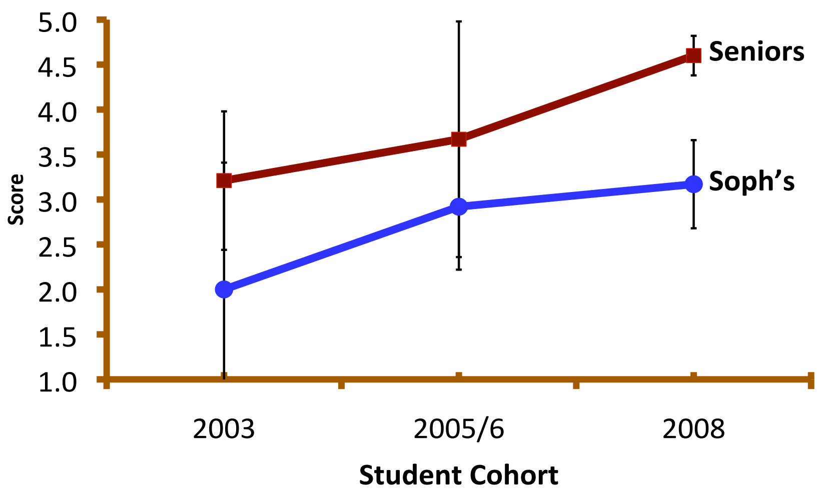



**Figure 12**. Designing accessible technical reports: Mean score overall.

***Document design.*** Good document design helps readers to follow even the most challenging technical arguments because the design of the text supports readers' needs for information processing (Schriver, 2006). Put differently, a well-designed report has a purpose-driven organization that is cued visually (e.g., through typography, contrast, proximity, or color) (Schriver, 1987).

The results of a two-way ANOVA (shown in Table 1, item 3.1, page 12) showed a significant main effect for document design of technical reports between pretest and posttest ($F$ = 13.345; $df$ = 1,16; $p$ = .002). The ANOVA also indicated a main effect for cohort ($F$ = 5.101; $df$ = 2,16; $p$ = .019). Follow-on Mann-Whitney U tests (see Table 6) showed that technical reports by seniors made more effective use of document design than did reports by sophomores in 2008. Analyses indicated that sophomores showed significant improvement in document design between 2003 and 2005 and between 2003 and 2008. In 2003 sophomores had a mean score of 1.50 ($SD$ = .71), in 2005/6 a mean score of 2.88 ($SD$ = .75), and in

2008, a mean score of 2.88 (*SD* = .48). Seniors also showed a significant improvement in document design between 2003 (*M* = 3.00, SD = 1.22) and 2008 (*M* = 4.75 (*SD* = .29).

**Table 6.** Mann-Whitney U results for accessibility of technical reports: Document design.

**Mann-Whitney U Analyses for Technical Reports: Document Design**

| Group | Cohort Year | Mann-Whitney[1] | MW U Stat[2] |
|---|---|---|---|
| Sophomores vs Seniors | 2003 | NS | |
| | 2005/6 | NS | |
| | 2008 | 0.009 | 0 |
| Sophomores (only) | 2003-2005 | 0.025 | 0.00 |
| | 2003-2008 | 0.025 | 0.00 |
| | 2005-2008 | NS | |
| Seniors (only) | 2003-2005 | NS | |
| | 2003-2008 | 0.009 | 0.0 |
| | 2005-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

Figure 13 displays the trends for students' performance in document design across cohort years. As shown, seniors make dramatic improvements from 2003 to 2008, while sophomores make substantial improvements from 2003 to 2005/6 and then level off for 2008.

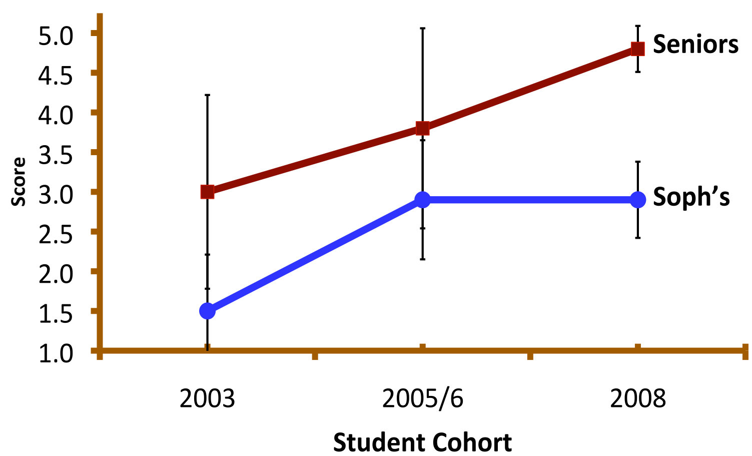



**Figure 13**. Designing accessible technical reports: Document design.

***Structure & hierarchy.*** When the *structure and hierarchy* of a technical report are working well, organizational cues provide an overall architecture for the document so that readers can easily anticipate how parts of the content fit together and what is coming next (Schriver, 1992).

A two-way ANOVA indicated a significant main effect for the structure and hierarchy of technical reports between pretest and posttest ($F$ = 9.184; $df$ = 1,16; $p$ = .008) (see Table 1, item 3.2, page 12). Mann-Whitney U tests showed technical reports by seniors in 2008 to be more effective in their use of structure and hierarchy than reports by sophomores (see Table 7). Seniors also showed a significant improvement in structure and hierarchy between 2003 and 2008, with mean scores of 3.38 in 2003 (SD = .63) and 4.50 in 2008 (*SD* = .41).

**Table 7.** Mann-Whitney U results for accessibility of technical reports: Structure & hierarchy.

| Mann-Whitney U Analyses for Technical Reports: Structure & Hierarchy | | | |
|---|---|---|---|
| **Group** | **Cohort Year** | **Mann-Whitney[1]** | **MW U Stat[2]** |
| **Sophomores vs Seniors** | 2003 | NS | |
| | 2005/6 | NS | |
| | 2008 | 0.014 | 0.5 |
| **Sophomores (only)** | 2003-2005 | NS | |
| | 2003-2008 | NS | |
| | 2005-2008 | NS | |
| **Seniors (only)** | 2003-2005 | NS | |
| | 2003-2008 | 0.014 | 0.5 |
| | 2005-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

Figure 14 presents the trends for student performance in structure and hierarchy. As shown, students tended to get better as the Cain Project became an integral part of the bioengineering curriculum.

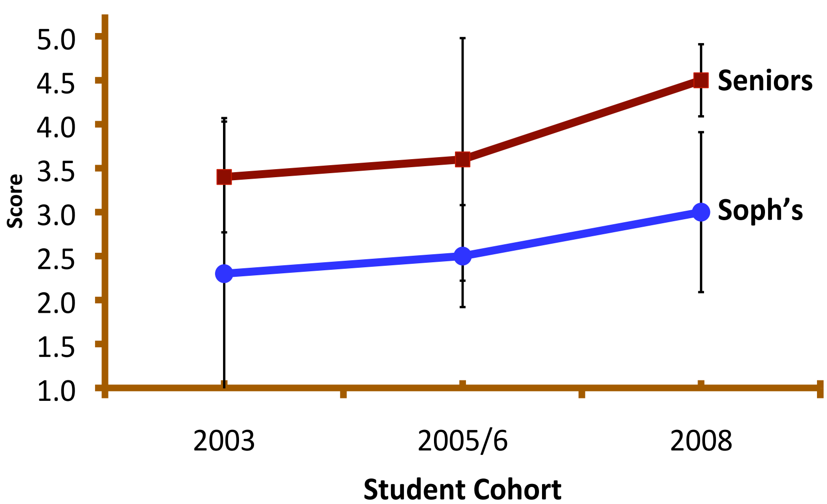



**Figure 14**. Designing accessible technical reports: Structure & hierarchy.

***Summaries & previews.*** Technical reports that are optimized for accessibility make use of summaries and previews. Both features help readers organize and interpret content.
A two-way ANOVA showed a marginally significant main effect for summaries and previews for cohort ($F$ = 2.771; $df$ = 2,16, $p$ = .093) (see Table 1, item 3.3, page 12). Follow-on Mann-Whitney U tests (presented in Table 8) showed that in 2008 seniors composed better

summaries and previews than sophomores. Seniors were also found to improve between 2003 and 2008. No significant changes for sophomores were found.

**Table 8.** Mann-Whitney U results for accessibility of technical reports: Summaries & previews.

| Mann-Whitney U Analyses for Technical Reports: Summaries & Previews | | | |
|---|---|---|---|
| Group | Cohort Year | Mann-Whitney[1] | MW U Stat[2] |
| Sophomores vs Seniors | 2003 | NS | |
| | 2005/6 | NS | |
| | 2008 | 0.053 | 2.5 |
| Sophomores (only) | 2003-2005 | NS | |
| | 2003-2008 | NS | |
| | 2005-2008 | NS | |
| Seniors (only) | 2003-2005 | NS | |
| | 2003-2008 | 0.029 | 1.5 |
| | 2005-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

Figure 15 presents a snapshot of students' performance for summaries and previews. As shown, sophomores trend in a positive direction, but there was considerable variability within cohorts, especially in 2003 and 2005/6. In 2003, sophomores had a mean score of 2.25 (*SD* = 1.77), in 2005/6, a mean score of 3.38 (*SD* = 1.11). The variability was considerably less in 2008, with a mean score of 3.63 (*SD* = .48). Seniors improved steadily with less variability than sophomores (see Appendix D, 3.3).

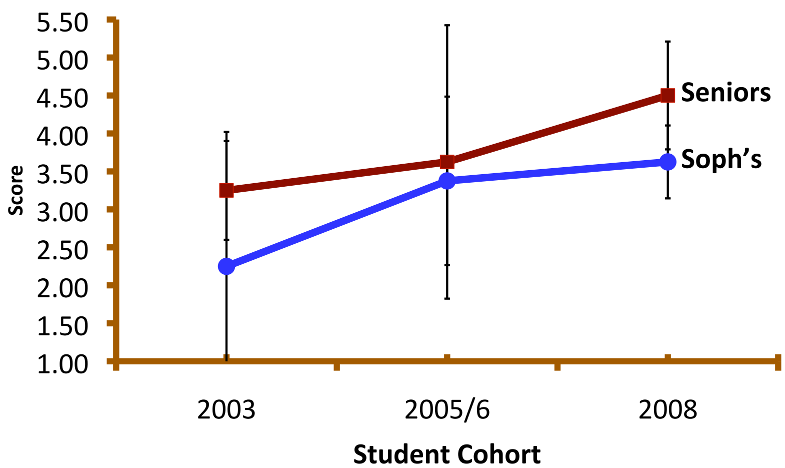



**Figure 15**. Designing accessible technical reports: Summaries & previews.

**Key Variable:** Intercultural/Interpersonal Awareness in Technical Reports

Intercultural/interpersonal awareness is revealed by rhetorical moves (visual or verbal) that together give an impression of the author's empathy for the reader's point of view. Readers expect to see detail that responds to their unique interests and needs (Schriver, 2009). There was no significant main effect for intercultural/interpersonal awareness overall; however, a two-way ANOVA showed a marginally significant effect for *sensitivity to audience* for pretest–posttest ($F = 3.939$; $df = 1,16$; $p = .065$) (see Table 1, item 4.1, page 12).

***Sensitivity to audience.*** When a report is sensitive to the audience, the text is written to show respect for readers through an appropriate level of complexity. Readers expect the content to connect to their knowledge, values, or assumptions about the topic. Moreover, readers of technical reports should not have to guess what authors intend; the text should be explicit, devoid of unnecessary jargon or metaphors that may lead to confusion.

Seniors' scores were better than those of sophomores at posttest for sensitivity to audience, with an overall mean score of 4.0, while sophomores had a mean score of 3.04. Sophomores trended in a positive direction: 2.75 in 2003 ($SD$ =1.77); 2.88 in 2005/6 ($SD$ = .85); 3.50 in 2008 ($SD$ = .82). However, these gains were not significant.

Follow-on Mann-Whitney U analyses for sensitivity to audience found no significant cohort effects for either sophomores or seniors (see Appendix F).

## Summary of Results and Discussion of Technical Reports

### Summary

Taken together, the analyses of students' technical reports speak to the performance of (1) sophomores over time, (2) seniors over time, and (3) sophomores versus seniors in the years 2003, 2005/6, and 2008.

***Sophomores' performance.*** The data show that for the most part sophomores—who were being introduced to the design of technical reports—did not change significantly from cohort-to-cohort. However, they did improve in some measures. For example, they developed significantly in "document design" (item 3.1). Students' scores also trended in a positive direction for "sensitivity to audience" (item 4.1), although not significantly so.

It is worth pointing out that some sophomores composed reports that were almost as good as seniors, suggesting they too were acquiring new skills in professional communication, but more often than not, sophomores' performance was uneven, tending to perform well in some sections of the report and poorly in others.

***Seniors' performance.*** By contrast, bioengineering seniors were found to improve significantly in the following areas of technical report design:

**Comprehensibility**
- Visual conventions (item 1.2)

**Persuasiveness**
- Technical approach (item 2.2)

**Accessibility**
- Accessibility overall (item 3)
- Document design (item 3.1)

Structure and hierarchy (item 3.2)
Summaries and previews (item 3.3)

**Intercultural/Interpersonal Effectiveness**

Sensitivity to audience (item 4.1)

The analyses show that between 2003 and 2008 seniors made steady progress in these areas of report design.

Moreover, in each of these areas of report design, seniors performed better than sophomores in either 2005/6 or 2008, but especially so in 2008, at the end of the Cain Project.

### Discussion

***Sophomores' performance.*** KSA's assessment of technical reports found that sophomores made significant improvements in the accessibility of their reports but not in the other areas. Sophomores' lack of improvement was largely due to inconsistencies in their reports (e.g., convincing in some sections while unconvincing in others). Previous research on writing-in-the-disciplines may help explain the uneven performance of sophomores. It suggests that we might expect inconsistency of performance when students are being introduced to their discipline and its unique rhetorical moves (Ackerman, 1999, Anson & Forsberg, 1990; Berkenkotter & Huckin, 1995; Winsor, 1996).

The report-writing task may have been more difficult for sophomore students because they were learning to write reports while simultaneously acquiring the subject-matter knowledge of their domain. Sophomores needed to immerse themselves in new knowledge about bioengineering and demonstrate their problem-solving ability within the framework of a genre with which they were largely unfamiliar. The scientific technical report is a tightly circumscribed genre that calls for more sophisticated writing and design skills than reports students may have produced in high-school or in a freshman writing course.

Students likely needed more time-on-task to become familiar with and practice the conventions of technical reports. Indeed, time-on-task has been shown to relate to performance in many domains (Anderson, 1993).

***Seniors' performance.*** In contrast, our assessment found that the Cain Project had a more pervasive impact on the design of seniors' technical reports. Seniors excelled in making their reports more accessible for readers through skillful document design and effective organization. Students also improved the visual conventions of their reports, which made them more comprehensible. Seniors' reports were more persuasive because their technical approach tended to be clear, compelling, and credibly articulated. Seniors also got better in making rhetorical moves that demonstrated their awareness of the audience's values and assumptions.

In addition, seniors' writing and design conveyed a sense that they "owned" their subject matter in ways that were not apparent in the reports of sophomores. Seniors seemed less focused on reporting the problem at hand and more directed toward arguing their perspective on the problem.

If the Cain Project were making a difference, we would expect that as students in bioengineering progressed through the curriculum, they would increasingly consolidate their knowledge and achieve a more consistently high level of performance in professional communication. The results of this assessment generally support these expectations. By the time bioengineering students were ready to graduate, they had for the most part consolidated their strengths in professional communication and could marshal an argument consistently, cogently, and with precision.

Moreover, seniors seemed to shift their rhetorical stance from "reporter of someone else's knowledge" to "creator of their own knowledge." Overall, the impact of the Cain Project on students' skill in designing effective technical reports was gradual but steady, with the best performance for seniors during the final years of the project.

We turn now to students' performance on technical posters.

## GENRE 2: BIOENGINEERS' PERFORMANCE ON SCIENTIFIC POSTERS

### Results for Posters

The second genre KSA assessed was scientific posters. As with the technical reports, we first consolidated students' performance for posters on each of the five key variables and the 15 sub-variables. These data are summarized as a 5-page table in Appendix G. This summary presents students' scores for pretest and posttest across the three student cohorts for each variable for posters.

Appendix G also shows the mean scores for each cohort, the standard deviations, and overall means for each of the 15 sub-variables that comprise the 5 key variables under evaluation.

Drawing on this data set, Appendix H consolidates the 15 sub-variables as a one-page snapshot of how students performed on posters for each of the five key variables: (1) comprehensibility, (2) persuasiveness, (3) accessibility, (4) intercultural/interpersonal effectiveness, and (5) usability.

In addition, Appendix H also presents the weighted mean scores of the five key variables from pretest to posttest for each cohort. In the same manner as we did for technical reports, we weighted students' scores to reflect teachers' pedagogical emphases, with variables #1–3 assigned a weight of 2, and variables #4–5 a weight of 1.

Appendix I presents of a summary of the follow-on Mann-Whitney U tests for posters. Below we present the main findings of our assessment of students' scientific posters. We begin with an overview of how students performed across the genre as a whole. We then detail the quantitative and qualitative findings for the five key variables and their sub-variables.

## Overall Performance for Posters

Two-way ANOVAs were conducted for the grand mean of the five key variables as well as for each variable separately. These results (displayed in Table 9) showed no significant effects overall for pretest-posttest or for cohort.

**Table 9.** Results for posters: Two-way analyses of variance.

| Results of ANOVAs for Posters[1] | | | | | |
|---|---|---|---|---|---|
| N = 24 12 Pretest; 12 Posttest | **Pretest-Posttest[2]** | **Cohort[3]** | **Interaction** | **MW[4]** | **Levene Test[5]** |
| **Grand Mean for 5 Key Variables** | | | | | |
| Weighted Means[6] | NS | NS | NS | | 0.032 |
| **1. Comprehensibility Overall** | NS | NS | NS | | NS |
| 1.1 Writing Conventions | NS | NS | NS | | NS |
| 1.2 Visual Conventions | NS | NS | NS | | NS |
| 1.3 Genre Conventions | NS | NS | **0.050*** | ✓ | NS |
| 1.4 Technical Content | NS | NS | NS | | NS |
| **2. Persuasiveness Overall** | NS | NS | NS | | NS |
| 2.1 Options/Solutions | — | — | — | | — |
| 2.2 Technical Approach | NS | NS | 0.062 | ✓ | NS |
| 2.3 Methods/Computations | NS | NS | NS | | 0.009 |
| 2.4 Strengths, Limits, Implications | — | — | — | | — |
| **3. Accessibility Overall** | NS | NS | NS | | NS |
| 3.1 Document Design | NS | NS | NS | | NS |
| 3.2 Structure & Hierarchy | NS | NS | NS | | 0.001 |
| 3.3 Summaries & Previews | NS | NS | NS | | NS |
| **4. Intercultural/Interpersonal Overall** | NS | NS | **0.018** | ✓ | 0.001 |
| 4.1 Sensitivity to Audience | NS | NS | **0.018** | ✓ | 0.001 |
| 4.2 Adapted to Culture/Situation | — | — | — | | — |
| **5. Usability Overall** | NS | NS | 0.057 | ✓ | 0.001 |
| 5.1 Content Fits Purpose | NS | NS | 0.077 | ✓ | 0.005 |
| 5.2 Explanations Useful | NS | NS | 0.075 | ✓ | 0.025 |

***** Numbers in **boldface** are significant at .05 level or greater; others are marginally significant.

[1] Two-way ANOVAs were conducted for each variable. Student score (1-5) was the dependent variable. The independent variables were the following: (1) cohort (1, 2, or 3—corresponding to graduation year) and (2) pretest-posttest (junior or senior).

[2] All juniors were coded as pretest participants; all seniors as posttest.

[3] There were 3 cohorts: (1) Class of 2003, (2) Class of 2005/6, (3) Class of 2008.

[4] Items checked indicate that follow-on Mann-Whitney U (MW) analyses were conducted for the following: (1) juniors vs seniors, (2) juniors only, and (3) seniors only for each of the three 3 cohorts: (1) Class of 2005, (2) Class of 2006/7, (3) Class of 2008.

[5] Levene's Test evaluates the null hypothesis that the error variance of the dependent variable is equal across groups. A significant Levene suggests non-homogenous variance.

[6] Weights were as follows: (1) comprehensibility = 2; (2) persuasiveness = 2; (3) accessibility = 2; (4) intercultural = 1; (5) usability = 1.

The trends in students' overall performance on posters are graphed in Figure 7 (shown earlier on page 10). The results of analyses of variance showed no significant pretest-posttest or cohort effects for any of the individual variables.

However, there were three significant interactions for poster design: (1) genre conventions (item 1.3); (2) intercultural/interpersonal effectiveness overall (item 4); and (3) sensitivity to audience (item 4.1). There were also four marginally significant interactions for the following: (1) technical approach (item 2.2), (2) usability overall (item 5), (3) content fits purpose (item 5.1), and (4) explanations useful (item 5.2).

As with the technical reports, for each significant and marginally significant finding, we conducted follow-on Mann-Whitney U tests. We now detail these seven findings following the sequence of significant results shown in Table 9.

### **Key Variable:** Comprehensibility of Posters

***Genre conventions.*** Scientific posters about research or engineering design need to be designed using comprehensible genre conventions, with panels organized into sections that viewers of posters expect (e.g., title, purpose, methods, results, and conclusions). The sequence of the panels should allow viewers to follow the narrative of the argument. Each panel should serve to meet viewers' expectations for a given aspect of the research (e.g., methods). Essentially, the poster displays the skeleton of the argument both visually and verbally. Details are usually supplied orally during the poster presentation.

An ANOVA revealed an interaction for genre conventions of posters ($F = 3.545$; $df = 2,18$; $p = .050$) (see Table 9, item 1.3, page 24). Follow-on Mann-Whitney analyses (shown in Table 10) indicate that seniors scored better on genre conventions in 2008 than did juniors. These effects are graphed in Figure 16.

**Table 10.** Mann-Whitney U results for comprehensibility of posters: Genre conventions.

| **Mann-Whitney U Analyses for Posters: Genre Conventions** | | | |
|---|---|---|---|
| **Group** | **Cohort Year** | **Mann-Whitney[1]** | **MW U Stat[2]** |
| **Juniors vs Seniors** | 2005 | NS | |
| | 2006/7 | NS | |
| | 2008 | 0.026 | 1.50 |
| **Juniors (only)** | 2005-2007 | NS | |
| | 2005-2008 | NS | |
| | 2007-2008 | NS | |
| **Seniors (only)** | 2005-2007 | NS | |
| | 2005-2008 | NS | |
| | 2007-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

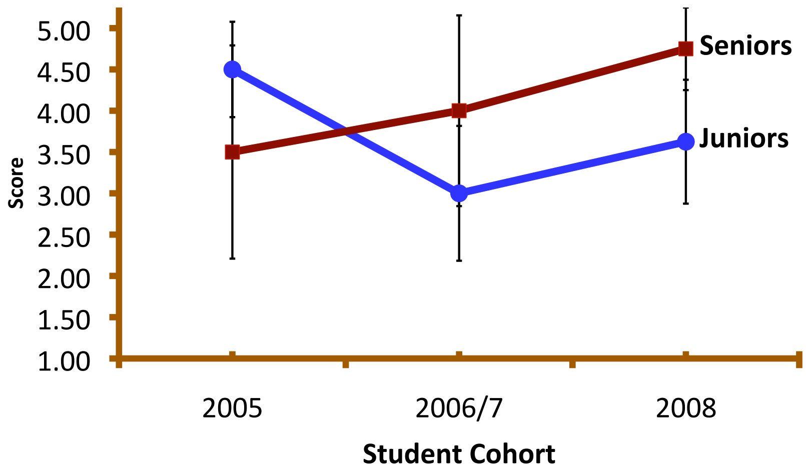



**Figure 16**. Designing comprehensible posters: Genre conventions.

**Key Variable:** Persuasiveness of Posters

***Technical approach.*** When the technical approach of a poster is good, the viewer of the poster is readily able to grasp the scope of the investigation, its experimental methods, and a snapshot of the results. Moreover, an effective technical approach employs visual and verbal language that allows experts in other scientific or technical domains to appreciate the investigation through rhetorical moves such as lack of jargon and clearly explicated charts, graphs, and quantitative displays.

The results of an ANOVA shown in Table 9 (item 2.2, page 24) showed a marginally significant interaction ($F = 3.259$; $df = 2{,}18$; $p = .062$). Follow-on Mann-Whitney analyses (shown in Table 11) indicate that seniors' posters illustrated a more persuasive technical approach in 2006/7 and in 2008 than did juniors. These improvements for technical approach are illustrated in Figure 17.

**Table 11.** Mann-Whitney U results for persuasiveness of posters: Technical approach.

| **Mann-Whitney U Analyses for Posters: Technical Approach** | | | |
|---|---|---|---|
| **Group** | **Cohort Year** | **Mann-Whitney[1]** | **MW U Stat[2]** |
| **Juniors vs Seniors** | 2005 | NS | |
| | 2006/7 | 0.031 | 2.00 |
| | 2008 | 0.041 | 2.50 |
| **Juniors (only)** | 2005-2007 | NS | |
| | 2005-2008 | NS | |
| | 2007-2008 | NS | |
| **Seniors (only)** | 2005-2007 | NS | |
| | 2005-2008 | NS | |
| | 2007-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

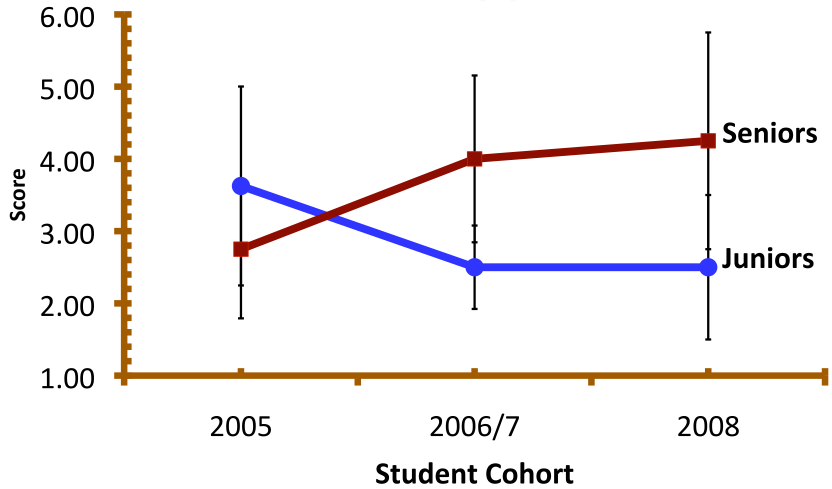



**Figure 17**. Designing persuasive posters: Technical approach.

**Key Variable:** Intercultural/Interpersonal Awareness in Poster Design

***Sensitivity to audience.*** When a technical poster is designed in ways that display awareness of the audience, readers (in Western countries) can readily follow the flow of the content by reading the text in columns from left to right. This left-to-right format also allows people who may be standing in line to read the poster to do so without bumping into one another (Nichol & Pexman, 2003). An additional consideration is the audience's physical proximity to text; here, the size of the typography and graphics should allow readers to inspect the content with ease while viewing it from several feet away.

More importantly, the visual and verbal content should have been selected to match the technical background and interests of the likely viewer. For example, photographs should depict only the content viewers need in order to better understand the subject and should be sized and cropped to enable viewers to see the key features immediately. Similarly, the poster's introduction and conclusion should tie into what the audience already knows about ongoing work on the topic, thus, connecting with their prior knowledge and elaborating it.

The results of the ANOVAs summarized in Table 9 (items 4 and 4.1, page 24) show a significant interaction for (1) interpersonal/intercultural awareness overall and (2) sensitivity to audience ($F = 5.050$; $df = 2,18$; $p = .018$). The scores for these two variables were identical because there was only one sub-variable scored under "interpersonal/intercultural awareness."

Coders found that students did not employ rhetorical moves in the design of their posters that illustrated their consideration of the second sub-variable "adapted to culture/situation" with enough frequency to score that sub-variable.

Follow-on Mann-Whitney U tests (shown in Table 12) indicate that seniors designed their posters with more intercultural/interpersonal awareness in 2008 than did juniors. Further, seniors improved significantly between 2005 and 2008. The trends in student performance are graphed in Figure 18.

**Table 12.** Mann-Whitney U results for intercultural/interpersonal effectiveness of posters: Sensitivity to audience.

| Mann-Whitney U Analyses for Posters: Sensitivity to Audience | | | |
|---|---|---|---|
| **Group** | **Cohort Year** | **Mann-Whitney[1]** | **MW U Stat[2]** |
| **Juniors vs Seniors** | 2005 | NS | |
| | 2006/7 | NS | |
| | 2008 | 0.010 | 0.00 |
| **Juniors (only)** | 2005-2007 | NS | |
| | 2005-2008 | NS | |
| | 2007-2008 | NS | |
| **Seniors (only)** | 2005-2007 | NS | |
| | 2005-2008 | 0.018 | 1.0 |
| | 2007-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

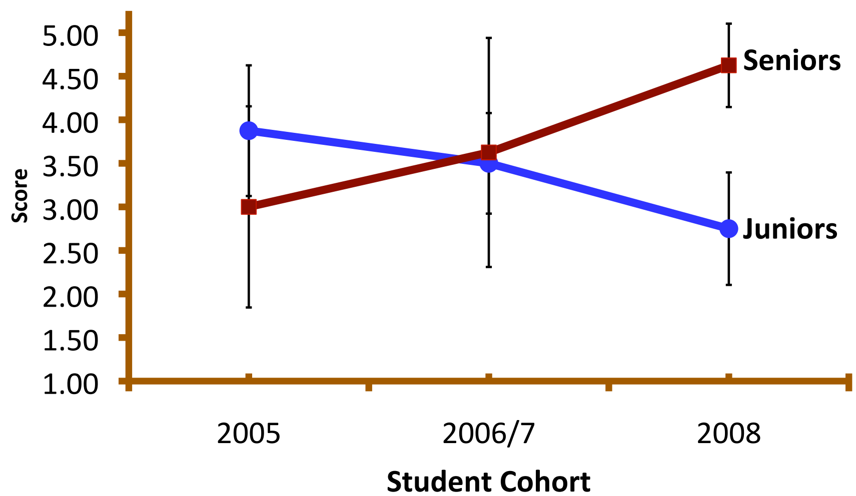



**Figure 18**. Intercultural/interpersonal effectiveness of posters: Sensitivity to audience.

**Key Variable:** Usability of Poster Design

***Grand mean for usability overall.*** When a poster is usable, viewers can find the important information quickly and easily because it is presented in a consistent and visually appealing manner.

The ANOVAs summarized in Table 9 (item 5, page 24) indicate a marginally significant interaction for usability overall ($F$ = 3.370; $df$ = 2,18; $p$ = .057). Follow-on Mann-Whitney analyses (presented in Table 13) showed that seniors created posters that were significantly more usable overall than juniors in 2008. Seniors also improved significantly between 2005-2008, a trend depicted in Figure 19.

**Table 13.** Mann-Whitney U results for usability of posters: Usability overall.

| Mann-Whitney U Analyses for Posters: Usability Overall | | | |
|---|---|---|---|
| **Group** | **Cohort Year** | **Mann-Whitney[1]** | **MW U Stat[2]** |
| **Juniors vs Seniors** | 2005 | NS | |
| | 2006/7 | NS | |
| | 2008 | 0.009 | 0.00 |
| **Juniors (only)** | 2005-2007 | NS | |
| | 2005-2008 | NS | |
| | 2007-2008 | NS | |
| **Seniors (only)** | 2005-2007 | NS | |
| | 2005-2008 | 0.016 | 1.0 |
| | 2007-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

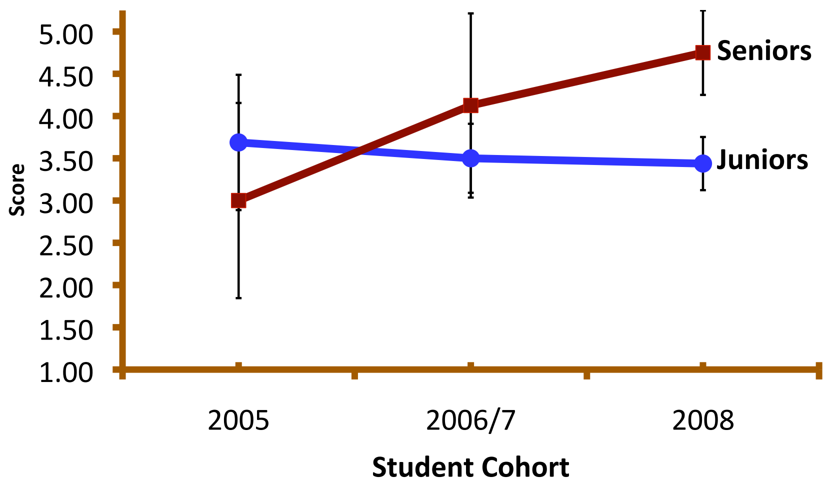



**Figure 19.** Usability of posters: Usability overall.

***Content fits purpose.*** When the content of a poster fits its purpose, each panel is designed so that readers can readily grasp the content and it significance to the overall investigation.

The results of an ANOVA summarized in Table 9 (item 5.1, page 24) show a marginally significant interaction for content fits purpose ($F = 2.973$; $df = 2,18$; $p = .077$). Follow-on Mann-Whitney U tests (see Table 14) reveal that seniors created posters in which the content matched the purpose more effectively than did juniors in 2008.

Seniors also significantly improved their performance between 2005 and 2008. These trends are displayed in Figure 20.

**Table 14.** Mann-Whitney U results for usability of posters: Content fits purpose.

| Mann-Whitney U Analyses for Posters: Content Fits Purpose | | | |
|---|---|---|---|
| **Group** | **Cohort Year** | **Mann-Whitney**[1] | **MW U Stat**[2] |
| **Juniors vs Seniors** | 2005 | NS | |
| | 2006/7 | NS | |
| | 2008 | 0.007 | 0.00 |
| **Juniors (only)** | 2005-2007 | NS | |
| | 2005-2008 | NS | |
| | 2007-2008 | NS | |
| **Seniors (only)** | 2005-2007 | NS | |
| | 2005-2008 | 0.007 | 0.0 |
| | 2007-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

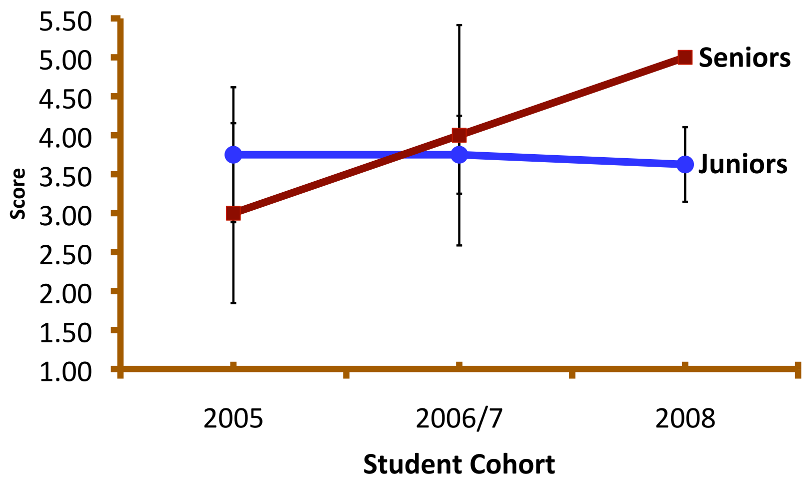



**Figure 20.** Usability of posters: Content fits purpose.

***Explanations useful.*** When a scientific poster's explanations are useful, every elaboration is purposeful and revealing of the main points. For example, posters often summarize the quantitative results through elaborative captions that guide and focus the viewer's attention to key aspects of the data.

The results of an ANOVA summarized in Table 9 (item 5.2, page 24) show a marginally significant interaction for useful explanations ($F$ = 3.000; $df$ = 2,18; $p$ = .075). Follow-on Mann Whitney analyses (see Table 15) found that in 2008 seniors designed their posters with explanations that were more effective than those designed by juniors.

As in the previous sub-variable of usability (content fits purpose), seniors improved in making their explanations useful between 2005 and 2008. Figure 21 plots these trends.

**Table 15.** Mann-Whitney U results for usability of posters: Explanations useful.

**Mann-Whitney U Analyses for Posters: Explanations Useful**

| Group | Cohort Year | Mann-Whitney[1] | MW U Stat[2] |
|---|---|---|---|
| Juniors vs Seniors | 2005 | NS | |
| | 2006/7 | NS | |
| | 2008 | 0.006 | 0.00 |
| Juniors (only) | 2005-2007 | NS | |
| | 2005-2008 | NS | |
| | 2007-2008 | NS | |
| Seniors (only) | 2005-2007 | NS | |
| | 2005-2008 | 0.007 | 0.0 |
| | 2007-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

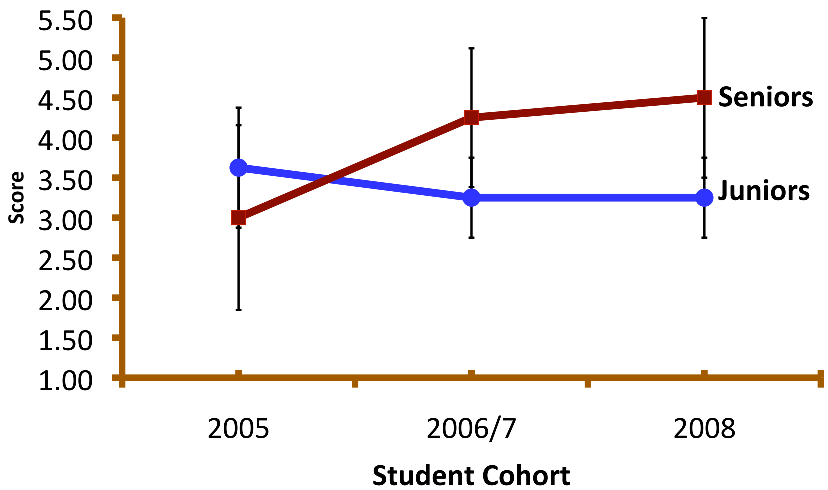



**Figure 21**. Usability of posters: Explanations useful.

## Summary of Results and Discussion of Posters

### Summary

Taken together, the analyses of students' scientific posters shed light on the performance of (1) juniors over time, (2) seniors over time, and (3) juniors versus seniors in 2005, 2006/7, and 2008.

***Juniors' performance.*** The data indicate that juniors had difficulty with generating effective scientific posters about their research. Juniors' scores did not improve significantly on either the five key variables or the 15 sub-variables. For the most part, juniors' performance fluctuated from year to year, with no clear patterns emerging.

***Seniors' performance.*** In contrast, seniors did show some significant improvements. Results of analyses of variance indicated a few significant and marginally significant interactions. The follow-on paired comparisons showed that seniors improved in several key areas of poster design between 2005 and 2008:

**Intercultural/Interpersonal Effectiveness**
Intercultural/interpersonal effectiveness overall (item 4)
Sensitivity to audience (item 4.1)
**Usability**
Usability overall (item 5)
Content fits purpose (item 5.1)
Explanations useful (item 5.2)

Paired comparisons of juniors versus seniors showed that seniors outperformed juniors in 2006/7 and in 2008 on *technical approach* (item 2.2). Analyses also found that seniors performed significantly better than juniors in 2008 in the following areas:

**Comprehensibility**
Genre conventions (item 1.3)
**Persuasiveness**
Technical approach (item 2.2)
**Intercultural/Interpersonal Effectiveness**
Intercultural/interpersonal effectiveness overall (item 4)
Sensitivity to audience (item 4.1)
**Usability**
Usability overall (item 5)
Content fits purpose (item 5.1)
Explanations useful (item 5.2

## Discussion

***Juniors' performance.*** Although some juniors produced excellent scientific posters, as a group they did not improve from cohort-to-cohort. It was not that students' scores were particularly low; most were above a score of 3 (out of the 5). Rather, there was considerable variability from student-to-student.

Students had trouble judging what content and how much content was appropriate to put on a single panel of their posters. Some students simply copied and pasted whole paragraphs from their technical reports into their posters.

***Seniors' performance.*** Both juniors and seniors were challenged by how much content to provide. Like many juniors, some seniors had difficulty recognizing when a panel had too much content. Instead of making judicious decisions about what content to omit, students tended to reduce the point size of the typography to fit in more content, which made the poster both visually dense and inconsistent because the type-size changed frequently.

A different persistent problem was that many students did not align their introduction with their conclusion. Students' summaries tended to cover more territory than had been previewed. They may have assumed that viewers would likely know the background of their study and readily determine how the plan and the execution added up. Or they may have believed they would fill in the gaps in person as they delivered their poster.

Either way, students needed to devote more attention to composing high-level overviews of their work, crisp syntheses of the data, and clear articulations of the results through well-designed figures and tables. Students' posters would have been better if the headings and subheadings were more purpose-oriented. Moreover, students needed to be more careful in making sure the content was integrated.

***The "poster" as an evolving genre.*** Posters do not usually function as stand-alone artifacts. However, increasingly, many are posted on the Web or viewed in a convention center without the author's presence. For example, the 2009 IEEE "Systems and Information Engineering Design Symposium" offers this advice: A poster should be able to "stand alone" without a presenter while slides for an oral presentation are designed to be accompanied by a presenter (http://www.sys.virginia.edu/sieds09/poster.html).

This advice from IEEE implies that the genre of "scientific poster" seems to be evolving requiring the poster to function *both* as a stand-alone artifact and as a vehicle for stimulating discussion. But this has not always been the case. Traditionally, the authors of a poster stand in front of it and discuss the work as they point to its different panels.

KSA knows that the Cain Project staff worked intensively with students to prepare them for answering questions about their posters. But this assessment was limited to the hardcopies of students' posters. We did not know what students had planned to say in presenting their posters or what questions from the audience they were ready to answer.

We suspect that perhaps the process of evaluating the posters "out of context" may have led to lower scores than if we had judged the actual poster presentations.

## GENRE 3: BIOENGINEERS' PERFORMANCE ON ORAL PRESENTATIONS

### Results for Oral Presentations

The third and final genre KSA assessed was oral presentations. As with the technical reports and posters, we first consolidated students' performance for oral presentations on each of the five key variables and 15 sub-variables.

The performance data is summarized as a 5-page table in Appendix J. This summary presents students' scores for pretest and posttest across the three student cohorts for each variable for oral presentations. Appendix J also shows the mean scores for each cohort, the standard deviations, and overall means for each of the 15 sub-variables.

Drawing on this data set, Appendix K consolidates the 15 sub-variables as a one-page snapshot of how students performed on oral presentations for each of the five key variables: (1) comprehensibility, (2) persuasiveness, (3) accessibility, (4) intercultural and interpersonal effectiveness, and (5) usability.

In addition, Appendix K also presents the weighted mean scores of the five key variables from pretest to posttest for each cohort. In the same manner as we did for technical reports and posters, we weighted students' scores to reflect teachers' pedagogical emphases, with variables #1–3 assigned a weight of 2, and variables #4–5 a weight of 1.

KSA also made one change in coding the first sub-variable under "comprehensibility" (see item 1.1 in Table 16, next page). Here, instead of coding students' performance for "writing conventions," we assessed students' use of "speaking conventions" (e.g., delivery, pacing, gestures, and eye contact).

Moreover, in making judgments about the quality of students' oral presentations, we evaluated both the writing and the design of their PowerPoint slides in addition to how well students elaborated their slides. Thus, for oral presentations, we assessed each of the variables by considering the coordination and overall effectiveness of the speaking, writing, and design.

Below we present the main findings of our assessment of students' oral presentations. We begin with an overview of how students performed across the genre as a whole. We then detail the findings for the five key variables and the 15 sub-variables.

### Overall Performance for Oral Presentations

As with the technical reports and posters, KSA first analyzed the oral presentation data using two-way ANOVAs for the five key variables and the 15 sub-variables. As before, student score was the dependent variable, while pretest-posttest and cohort were the independent variables.

Table 16 (on the next page) presents a summary of the ANOVA results for oral presentations. As shown, there were 30 significant main effects (and seven marginally significant main effects) for pretest-posttest or for cohort. There were no interactions. For each significant and marginally significant result, follow-on Mann-Whitney U tests were conducted (presented in Appendix L).

Table 16 indicates that students made significant improvements in the design of their oral presentations across all five key variables. We now detail these findings following the structure of Table 16.

***Grand mean overall.*** Table 16 (top) presents the results of an ANOVA for student performance collapsed over the five key variables. As shown, there was a significant main effect for pretest-posttest ($F = 9.829$; $df = 1{,}18$; $p = .006$) and for cohort ($F = 7.640$; $df = 2{,}18$; $p = .004$).

Follow-on Mann Whitney analyses are summarized in Table 17 (page 36). These tests indicate that seniors' oral presentations significantly improved between 2003 and 2005 and also between 2003 and 2008. There were no overall changes for sophomores. These trends are graphed in Figure 22 (page 36).

**Table 16.** Results for oral presentations: Two-way analyses of variance.

| Results of ANOVAs for Oral Presentations[1] | | | | | |
|---|---|---|---|---|---|
| N = 24 12 Pretest; 12 Posttest | **Pretest-Posttest[2]** | **Cohort[3]** | **Interaction** | **MW[4]** | **Levene Test[5]** |
| **Grand Mean for 5 Key Variables** | | | | | |
| Weighted Means[6] | **0.006*** | **0.004** | NS | ✓ | 0.024 |
| **1. Comprehensibility Overall** | 0.077 | **0.002** | NS | ✓ | 0.015 |
| 1.1 Speaking Conventions | NS | **0.014** | NS | ✓ | 0.005 |
| 1.2 Visual Conventions | NS | **0.001** | NS | ✓ | NS |
| 1.3 Genre Conventions | 0.072 | **0.023** | NS | ✓ | 0.001 |
| 1.4 Technical Content | 0.070 | NS | NS | ✓ | 0.007 |
| **2. Persuasiveness Overall** | **0.002** | 0.056 | NS | ✓ | NS |
| 2.1 Options/Solutions | **0.006** | NS | NS | ✓ | 0.012 |
| 2.2 Technical Approach | **0.007** | 0.068 | NS | ✓ | 0.021 |
| 2.3 Methods/Computations | **0.032** | **0.035** | NS | ✓ | 0.051 |
| 2.4 Strengths, Limits, Implications | **0.001** | NS | NS | ✓ | 0.049 |
| **3. Accessibility Overall** | **0.012** | **0.005** | NS | ✓ | NS |
| 3.1 Document Design | **0.027** | **0.001** | NS | ✓ | NS |
| 3.2 Structure & Hierarchy | **0.017** | **0.017** | NS | ✓ | 0.021 |
| 3.3 Summaries & Previews | **0.031** | 0.085 | NS | ✓ | 0.009 |
| **4. Intercultural/Interpersonal Overall** | **0.001** | **0.001** | NS | ✓ | 0.021 |
| 4.1 Sensitivity to Audience | **0.002** | **0.001** | NS | ✓ | 0.030 |
| 4.2 Adapted to Culture/Situation | **0.002** | **0.029** | NS | ✓ | 0.015 |
| **5. Usability Overall** | **0.021** | **0.005** | NS | ✓ | 0.017 |
| 5.1 Content Fits Purpose | **0.020** | **0.036** | NS | ✓ | 0.001 |
| 5.2 Explanations Useful | 0.079 | **0.003** | NS | ✓ | NS |

* Numbers in **boldface** are significant at .05 level or greater; others are marginally significant.

1 Two-way ANOVAs were conducted for each variable. Student score (1-5) was the dependent variable. The independent variables were the following: (1) cohort (1, 2, or 3—corresponding to graduation year) and (2) pretest-posttest (sophomore or senior).

2 All sophomores were coded as pretest participants; all seniors as posttest.

3 There were 3 cohorts: (1) Class of 2003, (2) Class of 2005/6, (3) Class of 2008.

4 Items checked indicate that follow-on Mann-Whitney U (MW) analyses were conducted for the following: (1) sophomores vs seniors, (2) sophomores only, and (3) seniors only for each of the three 3 cohorts: (1) Class of 2003, (2) Class of 2005/6, (3) Class of 2008.

5 Levene's Test evaluates the null hypothesis that the error variance of the dependent variable is equal across groups. A significant Levene suggests non-homogenous variance.

6 Weights were as follows: (1) comprehensibility = 2; (2) persuasiveness = 2; (3) accessibility = 2; (4) intercultural = 1; (5) usability = 1.

**Table 17.** Mann-Whitney U results for oral presentations over 5 key variables: Grand mean weighted.

| Mann-Whitney U Analyses for Oral Presentations: Grand Mean for 5 Key Variables | | | |
|---|---|---|---|
| **Group** | **Cohort Year** | **Mann-Whitney[1]** | **MW U Stat[2]** |
| **Sophomores vs Seniors** | 2003 | NS | |
| | 2005/6 | NS | |
| | 2008 | NS | |
| **Sophomores (only)** | 2003-2005 | NS | |
| | 2003-2008 | NS | |
| | 2005-2008 | NS | |
| **Seniors (only)** | 2003-2005 | 0.010 | 0 |
| | 2003-2008 | 0.010 | 0 |
| | 2005-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

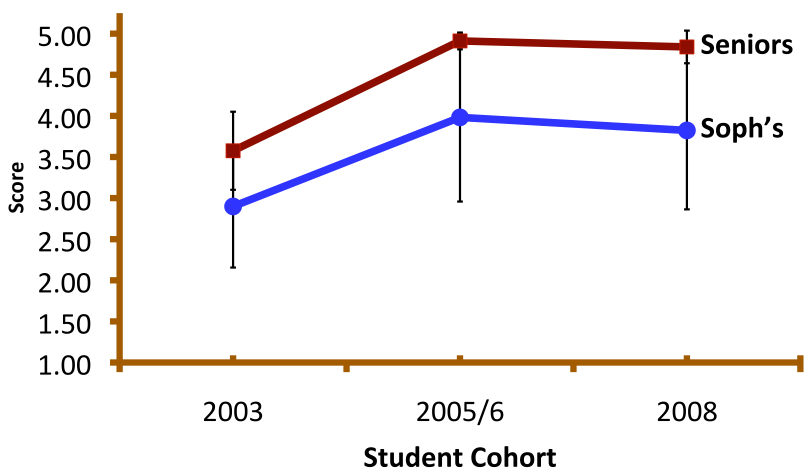



**Figure 22**. Designing effective oral presentations: Grand mean over 5 key variables.

**Key Variable:** Comprehensibility of Oral Presentations

***Grand mean for comprehensibility overall.*** Oral presentations that received high scores for overall comprehensibility were those in which students were engaging and articulate about their subject matter. Moreover, students made their points vivid for listeners by employing excellent visual conventions, by following the genre conventions of a well-organized speech, and by presenting their technical content in ways that were cogent and concise.

The results of ANOVAs, displayed in Table 16 (see item 1, page 35), show a significant main effect for cohort for overall comprehensibility of students' oral presentations ($F = 8.902$; $df = 1{,}18$; $p = .002$). There was also a marginally significant effect for pretest-posttest ($F = 3.518$, $df = 1{,}18$; $p = .077$). Follow-on Mann-Whitney tests (shown in Table 18) indicate that seniors made significant improvements in the overall comprehensibility of their oral presentations between 2003 and 2005 as well as between 2003 and 2008. These improvements are presented in Figure 23.

**Table 18.** Mann-Whitney U results for oral presentations: Comprehensibility overall.

| **Mann-Whitney U Analyses for Oral Presentations: Comprehensibility Overall** | | | |
|---|---|---|---|
| **Group** | **Cohort Year** | **Mann-Whitney[1]** | **MW U Stat[2]** |
| **Sophomores vs Seniors** | 2003 | NS | |
| | 2005/6 | NS | |
| | 2008 | NS | |
| **Sophomores (only)** | 2003-2005 | NS | |
| | 2003-2008 | NS | |
| | 2005-2008 | NS | |
| **Seniors (only)** | 2003-2005 | 0.009 | 0 |
| | 2003-2008 | 0.010 | 0 |
| | 2005-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

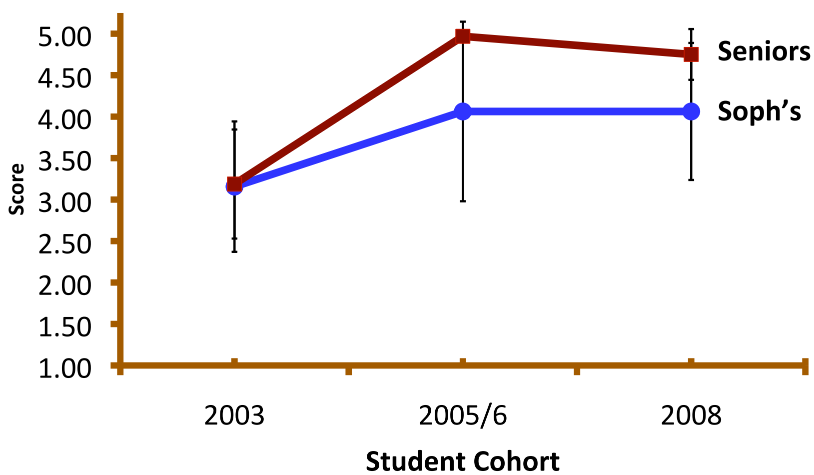



**Figure 23**. Designing comprehensible oral presentations: Comprehensibility overall.

***Speaking conventions.*** As mentioned earlier, a professional presentation is built on a foundation of excellent speaking conventions, such as delivery (voice quality, pronunciation, pitch, fluency, volume) pacing, gestures, body posture, and eye contact.

Results of an ANOVA (shown in Table 16, item 1.1, page 35) show a significant main effect for cohort ($F = 4.823$; $df = 2,18$; $p = .014$). Follow-on Mann-Whitney analyses (see Table 19) indicate a significant improvement for seniors in their use of speaking conventions between 2003 and 2005 as well as between 2003 and 2008. These improvements are graphed in Figure 24.

**Table 19.** Mann-Whitney U results for comprehensibility of oral presentations: Speaking conventions.

| Mann-Whitney U Analyses for Oral Presentations: Speaking Conventions | | | |
|---|---|---|---|
| **Group** | **Cohort Year** | **Mann-Whitney[1]** | **MW U Stat[2]** |
| **Sophomores vs Seniors** | 2003 | NS | |
| | 2005/6 | NS | |
| | 2008 | NS | |
| **Sophomores (only)** | 2003-2005 | NS | |
| | 2003-2008 | NS | |
| | 2005-2008 | NS | |
| **Seniors (only)** | 2003-2005 | 0.009 | 0 |
| | 2003-2008 | 0.010 | 0 |
| | 2005-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

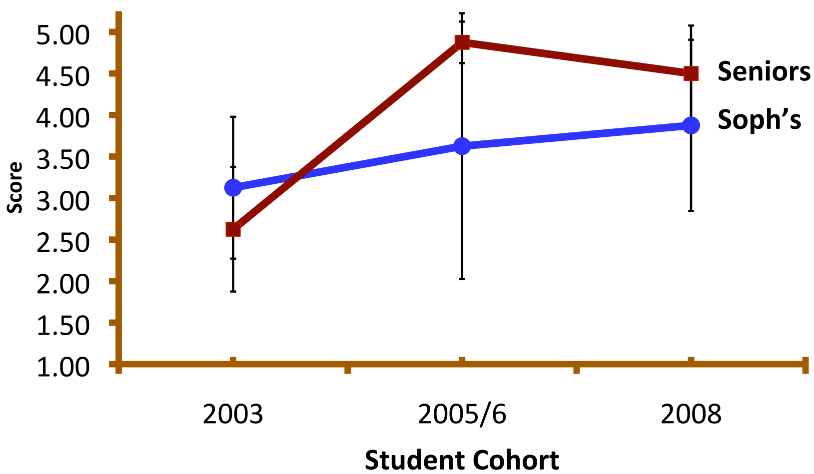



**Figure 24**. Designing comprehensible oral presentations: Speaking conventions.

***Visual conventions.*** Oral presentations that employ effective visual conventions are designed using typography, charts, diagrams, photos, animations, or videos that can be viewed easily from a distance under varying light levels. In addition, main points are presented succinctly, devoid of excessive detail or visual noise, and in aesthetically pleasing ways.

Results of an ANOVA (shown in Table 16, item 1.2, page 35) indicated a significant main effect for cohort ($F = 21.765$; $df = 2{,}18$; $p = .001$). Both sophomore and seniors improved in designing their PowerPoint slides with effective visual conventions. Follow-on Mann-Whitney analyses (see Table 20) suggest that sophomores improved significantly between 2003 and 2005. Seniors improved between 2003 and 2005 as well as between 2003 and 2008. These improvements are depicted graphically in Figure 25.

**Table 20.** Mann-Whitney U results for comprehensibility of oral presentations: Visual conventions.

| Mann-Whitney U Analyses for Oral Presentations: Visual Conventions | | | |
|---|---|---|---|
| **Group** | **Cohort Year** | **Mann-Whitney[1]** | **MW U Stat[2]** |
| **Sophomores vs Seniors** | 2003 | NS | |
| | 2005/6 | NS | |
| | 2008 | NS | |
| **Sophomores (only)** | 2003-2005 | 0.009 | 0 |
| | 2003-2008 | NS | |
| | 2005-2008 | NS | |
| **Seniors (only)** | 2003-2005 | 0.007 | 0 |
| | 2003-2008 | 0.013 | 0.50 |
| | 2005-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

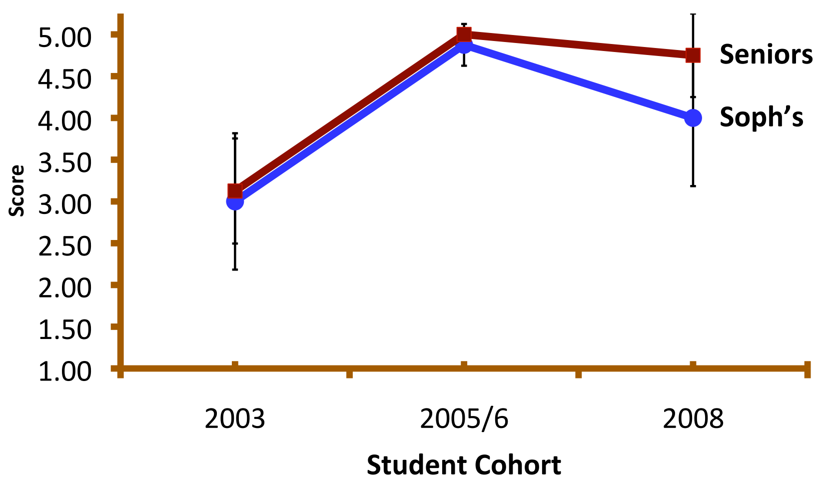



**Figure 25**. Designing comprehensible oral presentations: Visual conventions.

***Genre conventions.*** Speakers who follow the disciplinary genre conventions for technical and scientific presentations construct their talks to preview the content, frame the problem in the context of previous work, signal the main sections (e.g., introduction, methods, results), provide transitions, and employ charts, graphs, or other visuals in which use of colors, labels, and mathematical or statistical symbols are consistent. Technical presentations that adhere to genre conventions provide a summary, discuss the implications, and invite questions from the audience.

Results of an ANOVA (shown in Table 16, item 1.3, page 35) indicate a significant main effect for cohort on genre conventions ($F = 4.671$; $df = 1,18$; $p = .023$). There was also a marginally significant effect for pretest-posttest ($F = 3.657$; $df = 1,18$; $p = .072$). Mann-Whitney follow-on analyses show that the genre conventions seniors employed in their oral presentations improved between 2003 and 2005 as well as between 2003 and 2008. These trends are presented in Figure 26.

**Table 21.** Mann-Whitney U results for comprehensibility of oral presentations: Genre conventions.

| **Mann-Whitney U Analyses for Oral Presentations: Genre Conventions** | | | |
|---|---|---|---|
| **Group** | **Cohort Year** | **Mann-Whitney[1]** | **MW U Stat[2]** |
| **Sophomores vs Seniors** | 2003 | NS | |
| | 2005/6 | NS | |
| | 2008 | NS | |
| **Sophomores (only)** | 2003-2005 | NS | |
| | 2003-2008 | NS | |
| | 2005-2008 | NS | |
| **Seniors (only)** | 2003-2005 | 0.007 | 0 |
| | 2003-2008 | 0.010 | 0 |
| | 2005-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

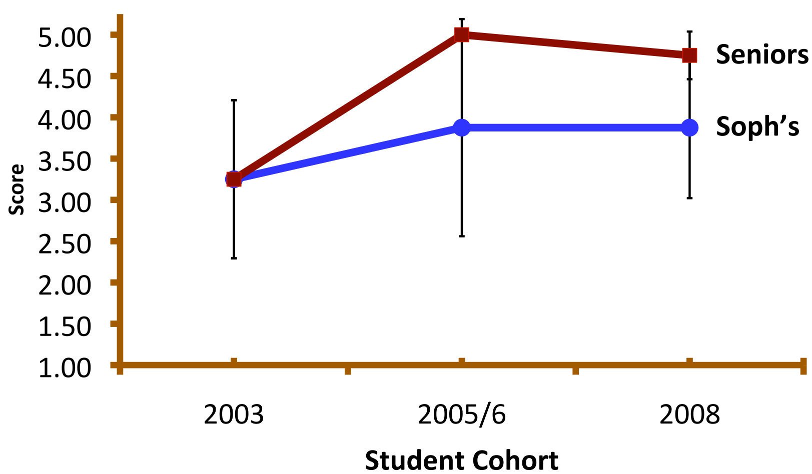



**Figure 26**. Designing comprehensible oral presentations: Genre conventions.

***Technical content.*** When the technical content of a presentation is strong, the speaker states the methods or approach in ways that make the scientific or technical subject matter clear to technical experts as well as to interested non-experts. Technical content is more comprehensible when the speaker presents the data collection techniques, analysis, and results in ways that demonstrate precise calculation, appropriate choice of analyses, and attention to detail. Well-designed slides present technical content in ways that allow listeners to judge the meaning of quantitative displays and statistics (e.g., through error bars, reliability coefficients, p values, etc.).

Results of an analysis of variance (presented Table 16, item 1.4, page 35) showed a marginally significant main effect for technical content ($F$=3.095; $df$ = 2,18; $p$ = .070). Mann-Whitney follow-on tests (see Table 22) suggest that seniors designed significantly more comprehensible technical content between 2003 and 2005 as well as between 2003 and 2008. Sophomores improved but not significantly so, a trend depicted in Figure 27.

**Table 22.** Mann-Whitney U results for comprehensibility of oral presentations: Technical content.

**Mann-Whitney U Analyses for Oral Presentations: Technical Content**

| Group | Cohort Year | Mann-Whitney[1] | MW U Stat[2] |
|---|---|---|---|
| Sophomores vs Seniors | 2003 | NS | |
| | 2005/6 | NS | |
| | 2008 | NS | |
| Sophomores (only) | 2003-2005 | NS | |
| | 2003-2008 | NS | |
| | 2005-2008 | NS | |
| Seniors (only) | 2003-2005 | 0.023 | 2 |
| | 2003-2008 | 0.023 | 2 |
| | 2005-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

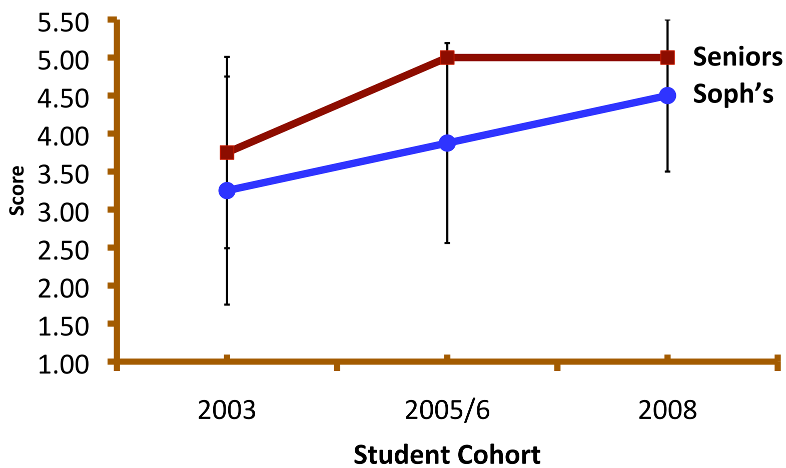



**Figure 27**. Designing comprehensible oral presentations: Technical content.

**Key Variable:** Persuasiveness of Oral Presentations

***Grand mean for persuasiveness overall.*** Oral presentations were persuasive overall when speakers provided a cogent discussion of options or possible solutions; when they articulated their argument and technical approach credibly; when they applied methods, techniques, models, or computations in a professional manner; and when they demonstrated awareness of the strengths, limitations, and implications of their work.

An ANOVA (see Table 16, item 2, page 35) showed a significant main effect for pretest-posttest ($F = 13.876$; $df = 1,18$; $p = .002$). Results also indicated a marginally significant main effect for cohort ($F = 3.402$; $df = 2,18$; $p = .056$). Follow-on Mann-Whitney tests (see Table 23) showed significant effects for overall persuasiveness, such that seniors outperformed sophomores in 2003, 2005/6, and 2008. Seniors also improved between 2003 and 2005 as well as between 2003 and 2008. These trends are shown in Figure 28.

**Table 23.** Mann-Whitney U results for oral presentations: Persuasiveness overall.

**Mann-Whitney U Analyses for Oral Presentations: Persuasiveness Overall**

| Group | Cohort Year | Mann-Whitney[1] | MW U Stat[2] |
|---|---|---|---|
| Sophomores vs Seniors | 2003 | 0.021 | 1.00 |
| | 2005/6 | 0.046 | 2.50 |
| | 2008 | 0.045 | 2.50 |
| Sophomores (only) | 2003-2005 | NS | |
| | 2003-2008 | NS | |
| | 2005-2008 | NS | |
| Seniors (only) | 2003-2005 | 0.009 | 0 |
| | 2003-2008 | 0.009 | 0 |
| | 2005-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

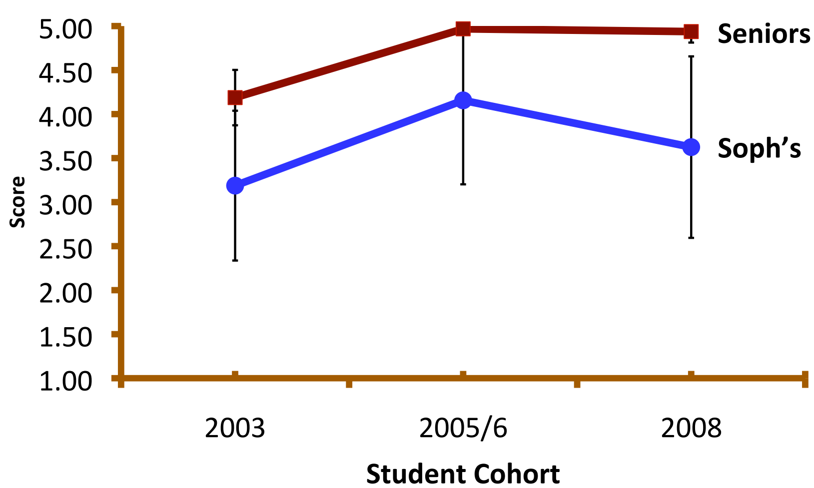



**Figure 28**. Designing persuasive oral presentations: Persuasiveness overall.

***Options/solutions.*** Speakers who performed well in presenting options or possible solutions to their inquiry demonstrated an awareness of one or more of the following: the previous research and/or earlier designs, the criteria for evaluating the adequacy of a solution, the feasibility of their solution, sustainability issues, or comparative advantages of their approach over the competition.

An ANOVA (shown in Table 16, item 2.1, page 35) showed a significant main effect for pretest-posttest ($F = 9.736$; $df = 1,18$; $p = .006$). A follow-on Mann-Whitney test (see Table 24) indicated that seniors outperformed sophomores in 2003 and in 2008. Seniors also improved between 2003 and 2008—trends shown in Figure 29.

**Table 24.** Mann-Whitney U results for persuasiveness of oral presentations: Options/solutions.

**Mann-Whitney U Analyses for Oral Presentations: Options/Solutions**

| Group | Cohort Year | Mann-Whitney[1] | MW U Stat[2] |
|---|---|---|---|
| Sophomores vs Seniors | 2003 | 0.049 | 3.00 |
| | 2005/6 | NS | |
| | 2008 | 0.023 | 2.00 |
| Sophomores (only) | 2003-2005 | NS | 0 |
| | 2003-2008 | NS | |
| | 2005-2008 | NS | |
| Seniors (only) | 2003-2005 | NS | |
| | 2003-2008 | 0.023 | 2 |
| | 2005-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

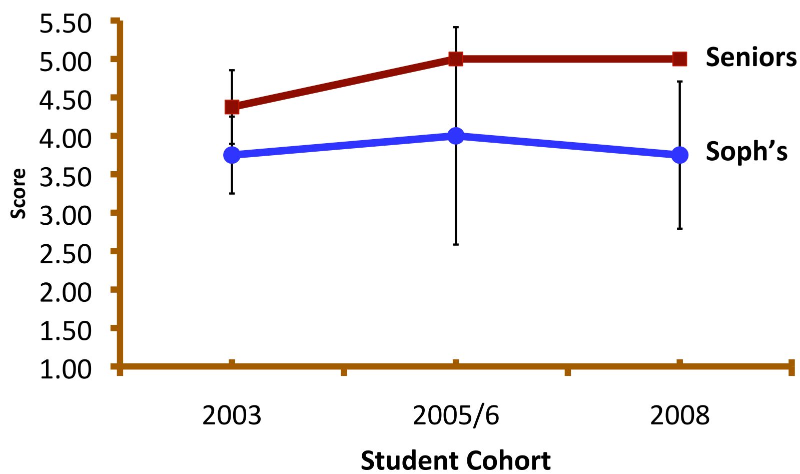



**Figure 29**. Designing persuasive oral presentations: Options/solutions.

***Technical approach.*** When oral presentations in scientific domains demonstrate an exemplary technical approach, speakers articulate how they explored or solved a problem (e.g., improved on existing technologies or developed new ones) in a methodologically credible manner. Listeners expect to hear not only what was done (e.g., what was unconventional or exceptionally innovative about the approach), but also the assumptions that underlie what was done, and the principles that guided decision-making.

An ANOVA (shown in Table 16, item 2.2, page 35) showed a significant main effect ($F$ = 9.075; $df$ = 1,18; $p$ = .007). Results also indicate a marginally significant main effect for cohort ($F$ = 3.137; $df$ = 2,18; $p$ = .068). Mann-Whitney follow-on tests show that seniors outperformed sophomores in 2008. Seniors also improved between 2003 and 2005 as well as between 2003 and 2008 (see Figure 30).

**Table 25.** Mann-Whitney U results for persuasiveness of oral presentations: Technical approach.

| Mann-Whitney U Analyses for Oral Presentations: Technical Approach | | | |
|---|---|---|---|
| **Group** | **Cohort Year** | **Mann-Whitney[1]** | **MW U Stat[2]** |
| **Sophomores vs Seniors** | 2003 | NS | |
| | 2005/6 | NS | |
| | 2008 | 0.024 | 2 |
| **Sophomores (only)** | 2003-2005 | NS | |
| | 2003-2008 | NS | |
| | 2005-2008 | NS | |
| **Seniors (only)** | 2003-2005 | 0.007 | 0 |
| | 2003-2008 | 0.023 | 2 |
| | 2005-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

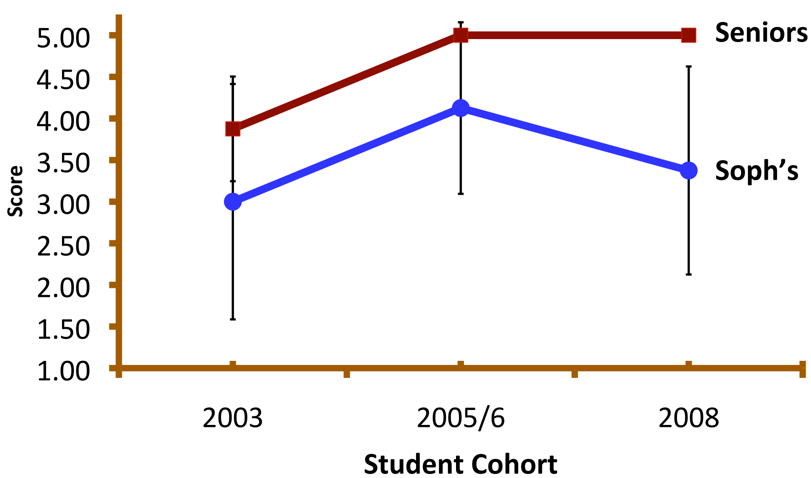



**Figure 30**. Designing persuasive oral presentations: Technical approach.

***Methods/computations.*** Speakers whose methods, models, analyses, or computations are persuasive make apparent their strategies for decision-making. Audiences expect transparency to enable judging the adequacy of the speaker's choices about, for example, theories, statistical tests, equations, techniques, or reliability. In short, speakers must demonstrate their ability to make principled quantitative and/or qualitative arguments.

An ANOVA (see Table 16, item 2.3, page 35) showed two main effects, one for pretest-posttest ($F = 5.385$; $df = 1,18$; $p = .032$) and one for cohort ($F = 4.043$; $df = 2,18$; $p = .035$). Follow-on Mann-Whitney tests indicated that in 2008 seniors performed significantly better than sophomores in the professional application of methods, techniques, computations and models (see Table 26). In addition, seniors performed better between 2003 and 2005 as well as between 2003 and 2008. These trends are plotted in Figure 31.

**Table 26.** Mann-Whitney U results for persuasiveness of oral presentations: Methods/computations.

**Mann-Whitney U Analyses for Oral Presentations: Methods/Computations**

| Group | Cohort Year | Mann-Whitney[1] | MW U Stat[2] |
|---|---|---|---|
| Sophomores vs Seniors | 2003 | NS | |
| | 2005/6 | NS | |
| | 2008 | 0.046 | 2.50 |
| Sophomores (only) | 2003-2005 | NS | |
| | 2003-2008 | NS | |
| | 2005-2008 | NS | |
| Seniors (only) | 2003-2005 | 0.007 | 0 |
| | 2003-2008 | 0.013 | 0.50 |
| | 2005-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

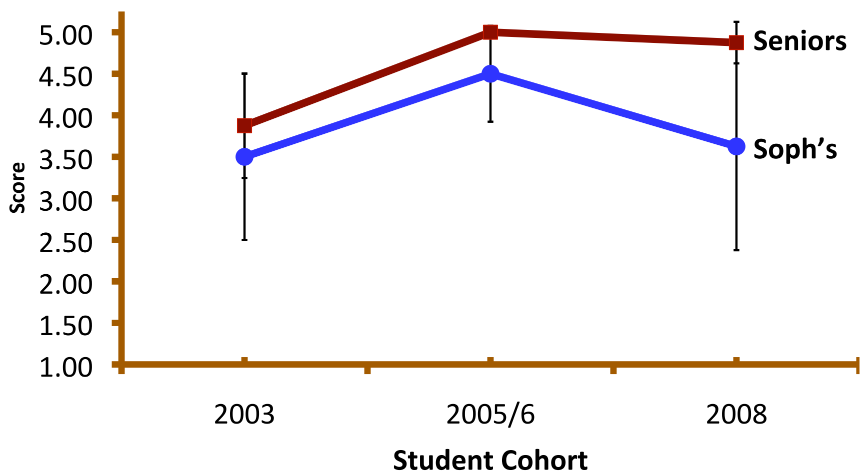



**Figure 31**. Designing persuasive oral presentations: Methods/computations.

***Strengths, limitations and implications.*** The best oral presentations in scientific domains are explicit about the initiative's strengths, weaknesses, and implications. Audiences expect speakers to position their work in its best light, while at the same time avoid overstating the case. Presentations are more persuasive when speakers make the strongest case for their work as well as raise the limitations of the endeavor.

An ANOVA (see Table 16, item 2.4, page 35) showed a main effect for pretest-posttest ($F$ = 16.584; $df$ = 1,18; $p$ = .001). Follow-on Mann-Whitney tests (shown in Table 27) indicate that in 2003 and 2008 seniors performed significantly better than sophomores in their articulation of strengths, weaknesses, limitations, and implications of their work. These improvements are graphed in Figure 32.

**Table 27.** Mann-Whitney U results for persuasiveness of oral presentations: Strengths, limitations and implications.

**Mann-Whitney U Analyses for Oral Presentations: Strengths, Limitations, Implications**

| Group | Cohort Year | Mann-Whitney[1] | MW U Stat[2] |
|---|---|---|---|
| Sophomores vs Seniors | 2003 | 0.014 | 0.50 |
| | 2005/6 | NS | |
| | 2008 | 0.045 | 2.50 |
| Sophomores (only) | 2003-2005 | NS | |
| | 2003-2008 | NS | |
| | 2005-2008 | NS | |
| Seniors (only) | 2003-2005 | NS | |
| | 2003-2008 | NS | |
| | 2005-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

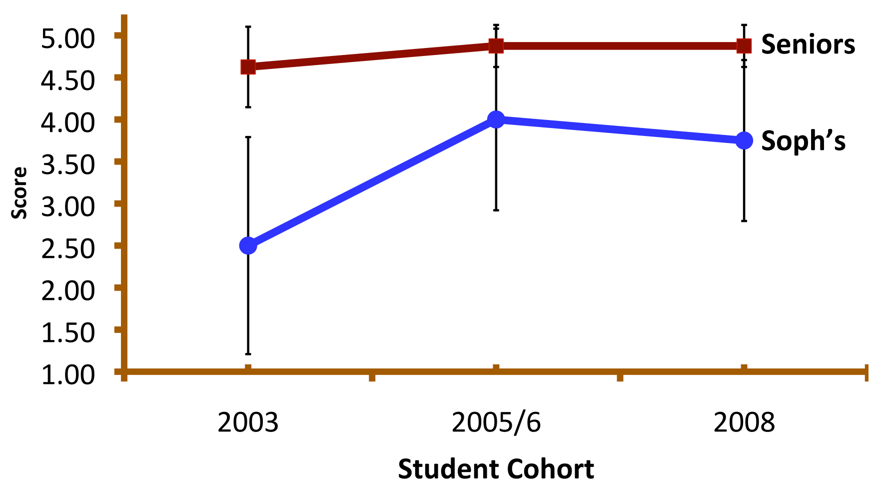



**Figure 32**. Designing persuasive oral presentations: Strengths, limitations, and implications.

**Key Variable:** Accessibility of Oral Presentations

***Grand mean for accessibility overall.*** When an oral presentation is effective in its accessibility overall, readers can anticipate what is coming next and can rapidly make appropriate inferences "about what is going on" when looking at slides. Three indicators of accessibility are

(1) document design, (2) structural cues that signal the hierarchy of content, and (3) summaries or previews that consolidate content.

An ANOVA (see Table 16, item 3, page 35) showed two main effects, one for pretest-posttest ($F = 7.750$; $df = 1,18$; $p = .012$) and one for cohort ($F = 7.111$; $df = 2,18$; $p = .005$). Follow-on Mann-Whitney tests indicated that sophomores improved significantly between 2003 and 2005 (see Table 28). Seniors performed better between 2003 and 2005 as well as between 2003 and 2008. These trends are plotted in Figure 33.

**Table 28.** Mann-Whitney U results for accessibility of oral presentations: Accessibility overall.

**Mann-Whitney U Analyses for Oral Presentations: Accessibility Overall**

| Group | Cohort Year | Mann-Whitney[1] | MW U Stat[2] |
|---|---|---|---|
| **Sophomores vs Seniors** | 2003 | NS | |
| | 2005/6 | NS | |
| | 2008 | NS | |
| **Sophomores (only)** | 2003-2005 | 0.041 | 2 |
| | 2003-2008 | NS | |
| | 2005-2008 | NS | |
| **Seniors (only)** | 2003-2005 | 0.010 | 0 |
| | 2003-2008 | 0.021 | 1 |
| | 2005-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

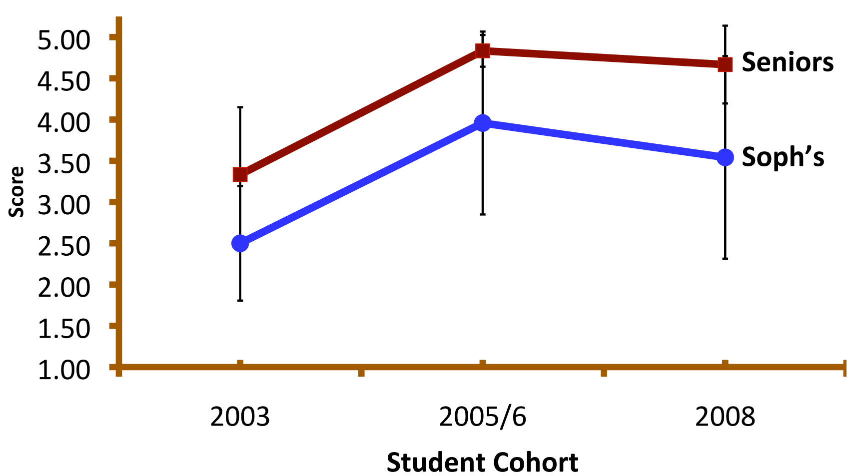



**Figure 33**. Designing accessible oral presentations: Accessibility overall.

***Document design.*** When the document design is strong, the slides employ purposeful and consistent patterns of visual and verbal organization. Visual strategies such as the use of contrast guide the viewer's eye to main points. Parallel headings promote scanning, enabling viewers to distinguish main points from minor ones. Effective document design not only makes the content more accessible, but it also presents the content—whether textual, graphical, or quantitative—in an aesthetically engaging manner.

An ANOVA (see Table 16, item 3.1, page 35) showed two main effects, one for pretest-posttest ($F = 5.769$; $df = 1,18$; $p = .027$) and one for cohort ($F = 10.442$; $df = 2,18$; $p = .001$). Follow-on Mann-Whitney tests (see Table 29) indicated that between 2003 and 2005 sophomores improved significantly in the document design of their oral presentations. Results also show that seniors performed better between 2003 and 2005 as well as between 2003 and 2008. These trends are plotted in Figure 34.

**Table 29.** Mann-Whitney U results for accessibility of oral presentations: Document design.

| Mann-Whitney U Analyses for Oral Presentations: Document Design | | | |
|---|---|---|---|
| **Group** | **Cohort Year** | **Mann-Whitney[1]** | **MW U Stat[2]** |
| **Sophomores vs Seniors** | 2003 | NS | |
| | 2005/6 | NS | |
| | 2008 | NS | |
| **Sophomores (only)** | 2003-2005 | 0.009 | 3.50 |
| | 2003-2008 | NS | |
| | 2005-2008 | NS | |
| **Seniors (only)** | 2003-2005 | 0.045 | 0 |
| | 2003-2008 | 0.045 | 3.00 |
| | 2005-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

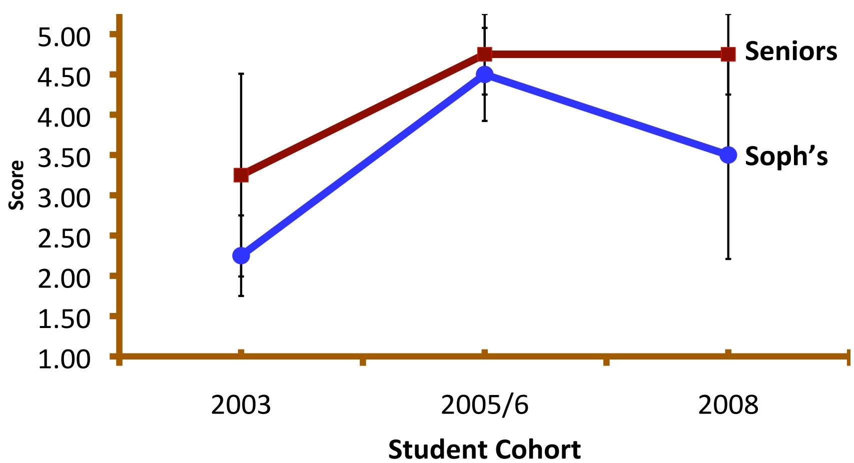



**Figure 34**. Designing accessible oral presentations: Document design.

***Structure and hierarchy.*** Oral presentations with good structure enable listeners to efficiently process the meaning, keep track of the organization, and anticipate what's coming next. Structure can be signaled by visual, spatial, and typographic cues. When an oral presentation has an effective structure, topics are developed in the order in which they are introduced, enabling listeners to form a coherent representation of the content.

An ANOVA (see Table 16, item 3.2, page 35) showed two main effects, one for pretest-posttest ($F = 6.943$; $df = 1,18$; $p = .017$) and one for cohort ($F = 5.152$; $df = 2,18$; $p = .017$). Follow-on Mann-Whitney tests (see Table 30) indicated that seniors improved in signaling the structure and hierarchy of their oral presentations between 2003 and 2005 as well as between 2003 and 2008. These trends are plotted in Figure 35.

**Table 30.** Mann-Whitney U results for accessibility of oral presentations: Structure & hierarchy.

| Mann-Whitney U Analyses for Oral Presentations: Structure & Hierarchy | | | |
|---|---|---|---|
| **Group** | **Cohort Year** | **Mann-Whitney[1]** | **MW U Stat[2]** |
| **Sophomores vs Seniors** | 2003 | NS | |
| | 2005/6 | NS | |
| | 2008 | NS | |
| **Sophomores (only)** | 2003-2005 | NS | |
| | 2003-2008 | NS | |
| | 2005-2008 | NS | |
| **Seniors (only)** | 2003-2005 | 0.013 | 0.5 |
| | 2003-2008 | 0.018 | 1 |
| | 2005-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

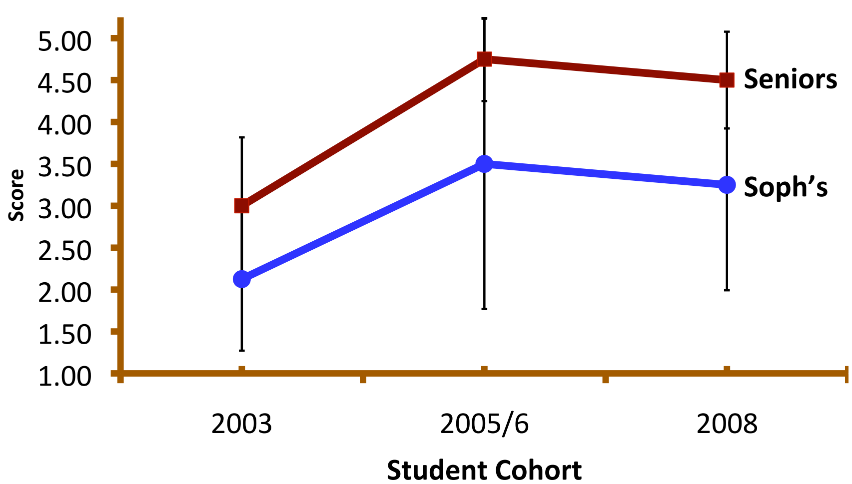



**Figure 35**. Designing accessible oral presentations: Structure & hierarchy.

***Summaries and previews.*** Effective summaries and previews enhance the accessibility of oral presentations by consolidating the main points succinctly (e.g., through itemized lists, overview graphics, or summary tables). By foreshadowing their content, speakers allow listeners to see how the pieces of the presentation fit together, guiding their comprehension and allowing them make appropriate inferences about the big picture.

An ANOVA (see Table 16, item 3.3, page 35) showed a main effect for pretest-posttest ($F$ = 5.490; $df$ = 1,18; $p$ = .031). Results also indicate a marginally significant effect for cohort ($F$ = 2.838; $df$ = 2,18; $p$ = .085). Follow-on Mann-Whitney tests (see Table 31) indicated that the summaries and previews designed by seniors were significantly better than those produced by sophomores in 2005/6. Seniors also showed improvement between 2003 and 2005. These trends are plotted in Figure 36.

**Table 31.** Mann-Whitney U results for accessibility of oral presentations: Summaries & previews.

| Mann-Whitney U Analyses for Oral Presentations: Summaries & Previews | | | |
|---|---|---|---|
| **Group** | **Cohort Year** | **Mann-Whitney**[1] | **MW U Stat**[2] |
| **Sophomores vs Seniors** | 2003 | NS | |
| | 2005/6 | 0.023 | 2 |
| | 2008 | NS | |
| **Sophomores (only)** | 2003-2005 | NS | |
| | 2003-2008 | NS | |
| | 2005-2008 | NS | |
| **Seniors (only)** | 2003-2005 | 0.023 | 2 |
| | 2003-2008 | NS | |
| | 2005-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

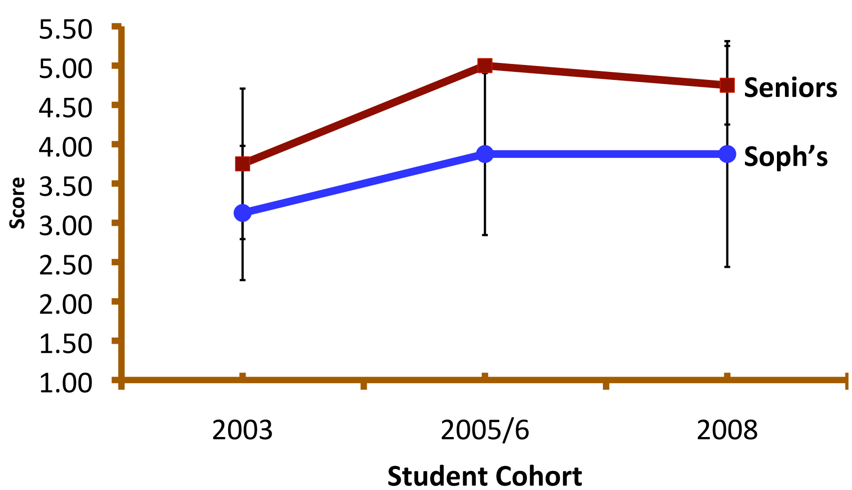



**Figure 36**. Designing accessible oral presentations: Summaries & previews.

**Key Variable:** Intercultural/Interpersonal Awareness in Oral Presentations

***Grand mean for intercultural/interpersonal effectiveness overall.*** Among the important indicators of intercultural and interpersonal awareness are (1) sensitivity to stakeholders' needs/expectations, and (2) adaptation to the listener's culture and situation.

An ANOVA (see Table 16, item 4, page 35) showed two main effects, one for pretest-posttest ($F = 17.436$; $df = 1,18$; $p = .001$) and one for cohort ($F = 9.869$; $df = 2,18$; $p = .001$). Follow-on Mann-Whitney tests (see Table 32) indicated that seniors were significantly better than sophomores in 2005/6 and in 2008. Sophomores showed improvement between 2003 and 2008. Seniors showed improvement between 2003 and 2005 as well as between 2003 and 2008. These trends are plotted in Figure 37.

**Table 32.** Mann-Whitney U results for oral presentations: Intercultural/interpersonal effectiveness overall.

| Mann-Whitney U Analyses for Oral Presentations: Intercultural/Interpersonal Effectiveness Overall | | | |
|---|---|---|---|
| **Group** | **Cohort Year** | **Mann-Whitney[1]** | **MW U Stat[2]** |
| **Sophomores vs Seniors** | 2003 | NS | |
| | 2005/6 | 0.024 | 2 |
| | 2008 | 0.024 | 2 |
| **Sophomores (only)** | 2003-2005 | NS | |
| | 2003-2008 | 0.015 | 0.50 |
| | 2005-2008 | NS | |
| **Seniors (only)** | 2003-2005 | 0.007 | 0 |
| | 2003-2008 | 0.007 | 0 |
| | 2005-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

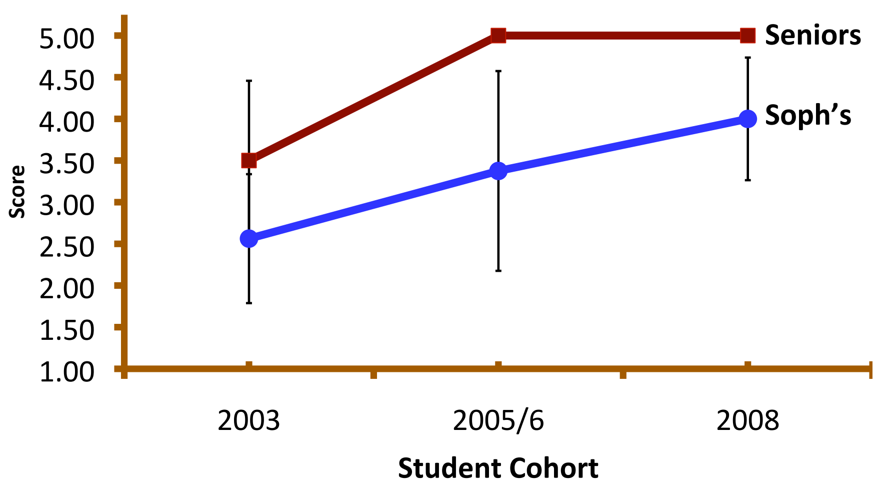



**Figure 37**. Designing oral presentations with intercultural/interpersonal awareness: Effectiveness overall.

***Sensitivity to audience.*** Technical presentations are responsive to the audience when speakers demonstrate they have anticipated stakeholders' knowledge, values, beliefs or assumptions about their topic. Presenters who are sensitive to their audience shape their content, elaborations, and examples to connect with the audience. Moreover, good presenters avoid using jargon or metaphors that may confuse listeners.

An ANOVA (see Table 16, item 4.1, page 35) showed two main effects, one for pretest-posttest ($F = 12.584$; $df = 1{,}18$; $p = .002$) and one for cohort ($F = 12.463$; $df = 2{,}18$; $p = .001$). Follow-on Mann-Whitney tests (see Table 33) indicated that the sensitivity to audience displayed by seniors was significantly better than that shown by sophomores in 2003, 2005/6, and 2008. Sophomores, however, made steady progress overall and a significant group improvement between 2003 and 2008. Seniors showed improvement between 2003 and 2005 as well as between 2003 and 2008 (see Figure 38).

**Table 33.** Mann-Whitney U results for intercultural/interpersonal effectiveness of oral presentations: Sensitivity to audience.

**Mann-Whitney U Analyses for Oral Presentations: Sensitivity to Audience**

| Group | Cohort Year | Mann-Whitney[1] | MW U Stat[2] |
|---|---|---|---|
| Sophomores vs Seniors | 2003 | 0.033 | 3 |
| | 2005/6 | 0.024 | 2 |
| | 2008 | 0.023 | 2 |
| Sophomores (only) | 2003-2005 | NS | |
| | 2003-2008 | 0.015 | 0.5 |
| | 2005-2008 | NS | |
| Seniors (only) | 2003-2005 | 0.023 | |
| | 2003-2008 | 0.023 | 0 |
| | 2005-2008 | NS | 0 |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

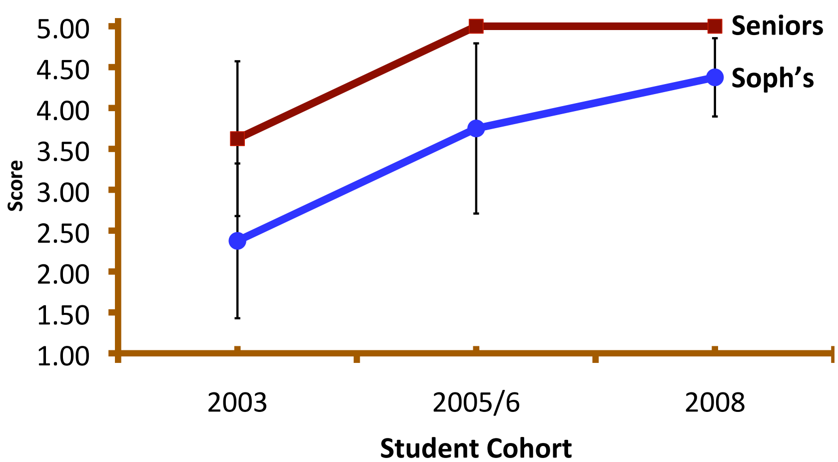



**Figure 38.** Designing oral presentations with intercultural/interpersonal effectiveness: Sensitivity to audience.

***Adapted to culture/situation.*** An oral presentation is adapted to the culture or situation when presenters connect explicitly to the audience's values and context. When speakers are effective, the audience is not "talked down to" nor "talked past," but are shown respect through the speaker's rhetorical moves. Effective speakers project a positive persona that shows listeners they have considered them through their visual and verbal choices.

An ANOVA (see Table 16, item 4.2, page 35) showed two main effects, one for pretest-posttest ($F = 13.593$; $df = 1,18$; $p = .002$) and one for cohort ($F = 4.314$; $df = 2,18$; $p = .029$). Follow-on Mann-Whitney tests (see Table 34) indicated that in 2005/6 and in 2008, seniors' were significantly better than sophomores in how their oral presentations were adapted to the audience's culture or situation. Seniors showed improvement between 2003 and 2005 as well as between 2003 and 2008 (see Figure 39).

**Table 34.** Mann-Whitney U results for intercultural/interpersonal effectiveness of oral presentations: Adapted to culture/situation.

**Mann-Whitney U Analyses for Oral Presentations: Adapted to Culture/Situation**

| Group | Cohort Year | Mann-Whitney[1] | MW U Stat[2] |
|---|---|---|---|
| **Sophomores vs Seniors** | 2003 | NS | |
| | 2005/6 | 0.023 | 2 |
| | 2008 | 0.024 | 2 |
| **Sophomores (only)** | 2003-2005 | NS | |
| | 2003-2008 | NS | |
| | 2005-2008 | NS | |
| **Seniors (only)** | 2003-2005 | 0.006 | 0 |
| | 2003-2008 | 0.006 | 0 |
| | 2005-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

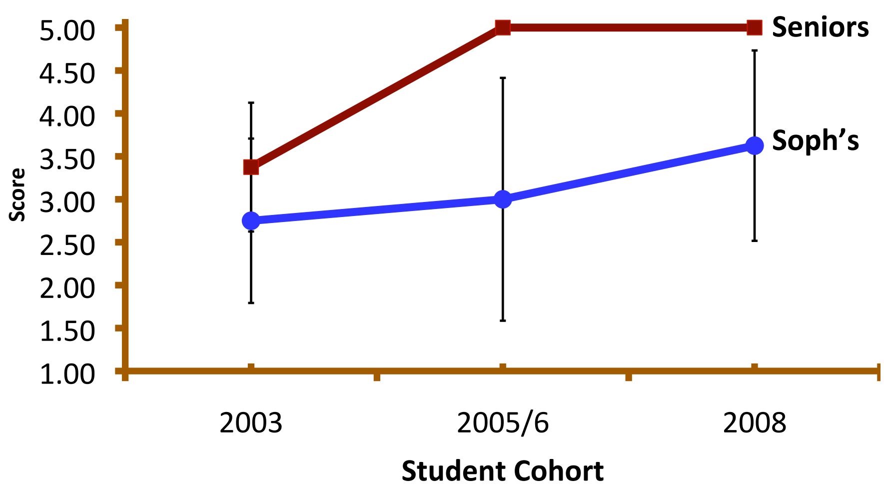



**Figure 39**. Designing oral presentations with intercultural/interpersonal effectiveness: Adapted to culture/situation.

**Key Variable:** Usability of Oral Presentations

***Grand mean for usability overall.*** A usable oral presentation fits the listener's likely purposes for attending the presentation. It provides information at the right level of detail for assessing the quality of the content and for following up on the ideas presented.

An ANOVA (see Table 16, item 5, page 35) showed two main effects, one for pretest-posttest ($F = 6.416$; $df = 1{,}18$; $p = .021$) and one for cohort ($F = 7.208$; $df = 2{,}18$; $p = .005$). Follow-on Mann-Whitney tests (see Table 35) indicated that in 2008 the overall usability of oral presentations created by seniors' was significantly better than those produced by sophomores. Seniors showed improvement between 2003 and 2005 as well as between 2003 and 2008. These trends are graphed in Figure 40.

**Table 35.** Mann-Whitney U results for usability of oral presentations: Usability overall.

**Mann-Whitney U Analyses for Oral Presentations: Usability Overall**

| Group | Cohort Year | Mann-Whitney[1] | MW U Stat[2] |
|---|---|---|---|
| Sophomores vs Seniors | 2003 | NS | |
| | 2005/6 | NS | |
| | 2008 | 0.024 | 2 |
| Sophomores (only) | 2003-2005 | NS | |
| | 2003-2008 | NS | |
| | 2005-2008 | NS | |
| Seniors (only) | 2003-2005 | 0.010 | 0 |
| | 2003-2008 | 0.007 | 0 |
| | 2005-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

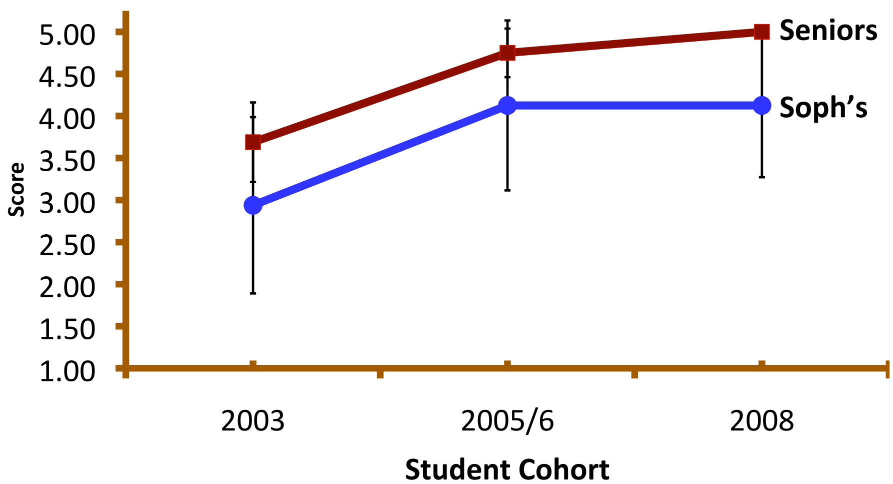



**Figure 40**. Designing usable oral presentations: Usability overall.

***Content fits purpose.*** When the content of an oral presentation matches the purposes listeners may have for attending the presentation (e.g., to learn, to decide, to choose, to update), the speaker structures the content with such interests in mind. Moreover, the speaker provides enough background to allow listeners to know whether the content is relevant to their purposes (e.g., by offering ideas about how to evaluate the results).

An ANOVA (see Table 16, item 5.1, page 35) showed two main effects, one for pretest-posttest ($F = 6.517$; $df = 1,18$; $p = .020$) and one for cohort ($F = 4.034$; $df = 2,18$; $p = .036$). Follow-on Mann-Whitney tests (see Table 36) indicated that seniors outperformed sophomores in 2003, and both sophomores and seniors improved significantly between 2003 and 2008. These trends are graphed in Figure 41.

**Table 36.** Mann-Whitney U results for usability of oral presentations: Content fits purpose.

| Mann-Whitney U Analyses for Oral Presentations: Content Fits Purpose | | | |
|---|---|---|---|
| **Group** | **Cohort Year** | **Mann-Whitney[1]** | **MW U Stat[2]** |
| **Sophomores vs Seniors** | 2003 | 0.024 | 2 |
| | 2005/6 | NS | |
| | 2008 | NS | |
| **Sophomores (only)** | 2003-2005 | NS | |
| | 2003-2008 | 0.039 | 2 |
| | 2005-2008 | NS | |
| **Seniors (only)** | 2003-2005 | NS | |
| | 2003-2008 | 0.004 | 0 |
| | 2005-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

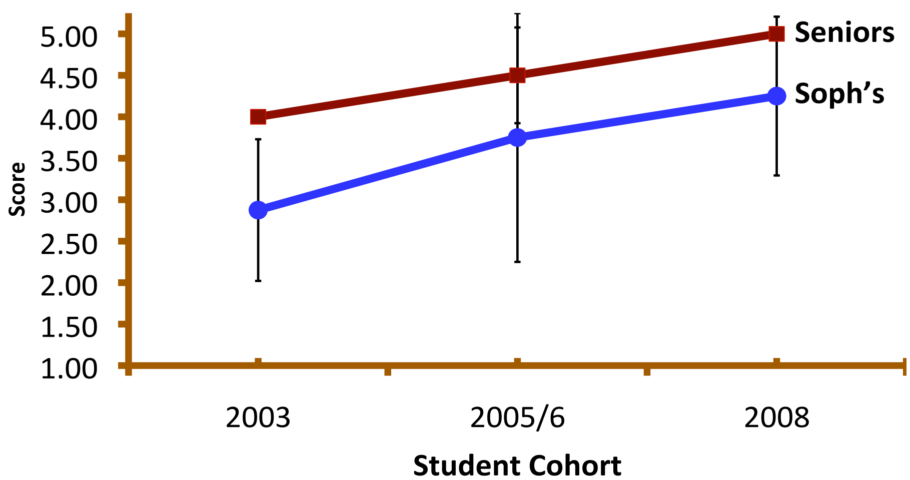



**Figure 41**. Designing usable oral presentations: Content fits purpose.

***Explanations useful.*** When a technical oral presentation is usable, its explanations, elaborations, and examples are purposeful, making the content both concrete and nuanced. Well-constructed explanations provide listeners with details relevant for evaluating what is said. It is often through the details that listeners gain a sense of the particularity and robustness of the technical or scientific content.

An ANOVA (see Table 16, item 5.2, page 35) showed a main effect for cohort ($F = 8.323$; $df = 2{,}18$; $p = .003$). Results also indicate a marginally significant effect for pretest-posttest ($F = 3.462$; $df = 1{,}18$; $p = .079$). Follow-on Mann-Whitney tests (see Table 37) indicate that in 2008 seniors performed significantly better in designing useful explanations than did sophomores. However, sophomores performed significantly better between 2003 and 2005. Seniors showed improvements between 2003 and 2005 and between 2003 and 2008. These trends are graphed in Figure 42.

**Table 37.** Mann-Whitney U results for usability of oral presentations: Explanations useful.

| Mann-Whitney U Analyses for Oral Presentations: Explanations Useful | | | |
|---|---|---|---|
| **Group** | **Cohort Year** | **Mann-Whitney[1]** | **MW U Stat[2]** |
| **Sophomores vs Seniors** | 2003 | NS | |
| | 2005/6 | NS | |
| | 2008 | 0.023 | 2 |
| **Sophomores (only)** | 2003-2005 | 0.040 | 2 |
| | 2003-2008 | NS | |
| | 2005-2008 | NS | |
| **Seniors (only)** | 2003-2005 | 0.007 | 0 |
| | 2003-2008 | 0.007 | 0 |
| | 2005-2008 | NS | |

[1] One-tailed p-value (significance level set at .05)
[2] The Mann-Whitney U statistic

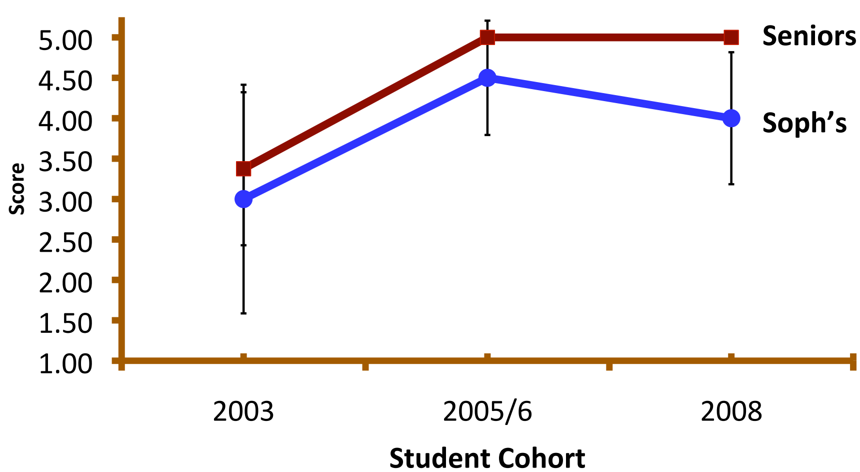



**Figure 42**. Designing usable oral presentations: Explanations useful.

## Summary of Results and Discussion of Oral Presentations

Taken together, the analyses of students' oral presentations speak to the performance of (1) sophomores over time, (2) seniors over time, and (3) sophomores versus seniors in 2003, 2005/6, and 2008.

### Summary

***Sophomores' performance.*** Overall, the Mann-Whitney analyses indicate that sophomores made significant gains in the following areas of their oral presentations between 2003 and 2005 or between 2003 and 2008:

**Comprehensibility**
- Visual conventions (item 1.2)

**Accessibility**
- Accessibility overall (item 3)
- Document design (item 3.1)

**Intercultural/Interpersonal Effectiveness**
- Intercultural/interpersonal overall (item 4)
- Sensitivity to audience (item 4.1)

**Usability**
- Content fits purpose (item 5.1)
- Explanations useful (item 5.2)

As the data show, sophomores improved most in making their presentations comprehensible, accessible, and usable for listeners. Sophomores adapted their content to meet the audience's expectations by providing clear and relevant details and by offering engaging explanations of the fine points of their work. Sophomores also improved in creating PowerPoint slides that were visually clear and well organized, making it easy for viewers to distinguish main points from minor ones. Sophomores also improved in presenting interesting details about the target populations for their work, demonstrating empathy for users of their work and showing a clear sense of ethical responsibility.

***Seniors' performance.*** In contrast, the follow-on paired comparisons of seniors' oral presentations showed that students improved significantly between 2003 and 2005 or between 2003 and 2008 on the following measures—the grand mean overall, the five key variables, and 14 of 15 sub-variables:

**Grand mean over the five key variables**

**Comprehensibility**
- Comprehensibility overall (item 1)
- Speaking conventions (item 1.1)
- Visual conventions (item 1.2)
- Genre conventions (item 1.3)
- Technical content (item 1.4)

**Persuasiveness**
- Persuasiveness overall (item 2)
- Options/solutions (item 2.1)
- Technical approach (item 2.2)
- Methods/computations (item 2.3)

**Accessibility**
- Accessibility overall (item 3)
- Document design (item 3.1)
- Structure & hierarchy (item 3.2)
- Summaries & previews (item 3.3)

**Intercultural/Interpersonal Effectiveness**

Intercultural/interpersonal overall (item 4)
Sensitivity to audience (item 4.1)
Adapted to culture/situation (item 4.2)

**Usability**

Usability overall (item 5)
Content fits purpose (item 5.1)
Explanations useful (item 5.2)

The only variable on which seniors did not improve significantly was "strengths, limitations, and implications" (item 2.4). This finding reflects a ceiling effect as students in the first cohort (2003) started out quite well, with a mean score of 4.63 (*SD* = .48). Similarly, students in the third cohort (2008) ended well, with a mean score of 4.79 (*SD* = .25) (see Figure 32, page 46). Thus, students had little room to improve.

Paired comparisons of sophomores versus seniors showed that seniors outperformed sophomores in the following areas in 2003, 2005/6, and/or 2008:

**Persuasiveness**

Persuasiveness overall (item 2)
Options/solutions (item 2.1)
Technical approach (item 2.2)
Methods/computations (item 2.3)
Strengths, limitations, implications (item 2.4)

**Accessibility**

Summaries & previews (item 3.3)

**Intercultural/Interpersonal Effectiveness**

Intercultural/interpersonal overall (item 4)
Sensitivity to audience (item 4.1)
Adapted to culture/situation (item 4.2)

**Usability**

Usability overall (item 5)
Content fits purpose (item 5.1)
Explanations useful (item 5.2)

## Discussion

***Sophomores' performance.*** This assessment of student performance tells us that sophomores made a number of significant improvements in designing their oral presentations. Sophomores made dramatic progress in the visual display of their PowerPoint slides and grew more adept in signaling the structure of their talks, which increased the comprehensibility and accessibility of their work substantially.

Sophomores also showed genuine concern for the populations who could benefit from their research. Listeners could readily sense students' empathy for the people whose lives might be influenced by their work. Sophomores provided useful explanations of how their projects could benefit, for example, a dialysis patient's quality of life, comfort, and safety. Because students connected their design choices to real-world concerns of patients, their oral presentations went beyond explicating equations and models to making clear they had thought deeply about the impact of their projects.

An important area that sophomores still needed to work on was their "speaking conventions." Quite a few of the sophomores tended to stare at their slides or the screens of their laptops instead of looking at the audience. Some spoke too quickly, while others made awkward gestures with their hands, revealing nervousness.

A different speaking problem was a failure to go beyond the content presented on their slides, with many students reading their slides word-for-word. Sophomores tended to focus on making sure they covered every bullet point rather than on persuading the audience of the adequacy of their technical approach and quantitative savvy.

***Seniors' performance.*** In contrast, this assessment found that seniors made clear gains in almost every area of oral presentation design. Like sophomores, they developed their skill in giving listeners a good sense of the structure of their talks. But unlike sophomores, seniors tended to re-iterate "where they were going" in their slides and in their elaborations, making it easy for listeners to track the technical argument across team members' presentations. Seniors also made better connections than sophomores between the introductions and conclusions of their talks, providing a more coherent depiction of their work.

Seniors exhibited a confidence about their subject-matter knowledge that sophomores rarely showed. Seniors were able to use their slides to catalyze their explanations rather than to remind them of what to say. Seniors did not wilt during question-and-answer sessions and seemed eager to elaborate their ideas. Seniors also came to their presentations dressed more professionally than sophomores and seemed to take the task more seriously.

Like sophomores, seniors made clear their concern for the people who might benefit from their research by supplying interesting details about how their projects might lead to lower costs for patients, better quality of life, easy-to-use devices, fewer hospital visits, and customized treatments. An advantage of seniors' presentations was that they often supported these details with excellent quantitative data that demonstrated the relative efficacy of their approach over others.

In addition, many seniors took their claims a step further with animated models, drawings, or devices that impressively showed the advantages of their approach in real time. Seniors also displayed sensitivity to a broader demographic than sophomores—from infants to the elderly, from able-bodied to disabled, from patients in industrialized countries to those in developing countries.

Overall, seniors made considerable strides in communicating their technical subject matter professionally to a critical audience. Most seniors did an excellent job of making a credible case for their research, while they also carefully hedged their claims and avoided overstating. Seniors grew skilled in pointing out the limitations of their processes, testing procedures, or products themselves—recognizing that they should do it before a member of the audience did it for them.

Seniors also excelled in detailing their proofs of concept and could readily tell the story of their work in compelling ways. Seniors were good at tailoring their arguments for the various constituents who might be in the audience—from the technical expert to the research and development manager to the venture capitalist.

Moreover, seniors were better than sophomores at positioning their work in a larger context and could readily talk about "what it meant" and "next steps." By senior year, students were skilled in presenting a broad vision of their work yet they could also drill down to details with ease, demonstrating their breadth and depth of knowledge in bioengineering.

Clearly, the Cain Project had a dramatic impact on seniors' enhanced oral presentation skills and their overall effectiveness as professional communicators. The net effect was oral presentations that were fascinating, informative, visually compelling, and engaging for the audience.

## DISCUSSION OF ASSESSMENT

This assessment was organized around the central question, "did the Cain Project have an impact on bioengineering student performance in professional communication?" To address this question of student outcomes, we first characterize overall trends in the data for technical reports, technical posters, and oral presentations.

Table 38 (on the next page) presents a summary view of students' improvements across the three genres. This summary identifies significant improvements found at the .05 level or less by analyses of variance and/or Mann-Whitney U tests.

The check marks on table 38 indicate improvements for seniors while check pluses refer to results in which both seniors and sophomores improved. (Juniors are not mentioned because they participated only in the second genre, posters, and did not show significant gains in any of the comparisons).

## Impact of Cain Project Across the Three Genres

To answer the question of whether students improved in their professional communication skills from sophomore to senior year, we now examine the impact of the Cain Project on the three genres. In looking across the data, two general trends emerged:

- Students improved dramatically in oral presentations
- Students improved moderately in technical reports and posters

Before exploring these trends, we should point out that during the six-year period we assessed, a variety of improvements to courses in bioengineering were made that may have contributed to the results. There was, of course, the Cain Project; but there was also the introduction of problem-based learning in sophomore classes and the refinement of collaborative design projects in the senior capstone course. In addition, students may have had opportunities to practice one or more of the three genres in courses not studied in this assessment.

**Table 38.** Improvements in bioengineers' performance in professional communication across the three genres.

| Summary of Significant Improvements Across the Three Genres | | | |
|---|---|---|---|
| **Key Variables and Sub-variables** | **Technical Reports** | **Technical Posters** | **Oral Presentations** |
| Grand Mean Over Five Key Variables | √ | | √ |
| **1 Comprehensibility Overall** | | | √ |
| 1.1 Writing/Speaking Conventions | | | √ |
| 1.2 Visual Conventions | √ | | √+ |
| 1.3 Genre Conventions | | √ | √ |
| 1.4 Technical Content | | | √ |
| **2 Persuasiveness Overall** | | | √ |
| 2.1 Options/Solutions | | | √ |
| 2.2 Technical Approach | √ | √ | √ |
| 2.3 Methods/Computations | | | √ |
| 2.4 Strengths, Limitations, Implications | | | √ |
| **3 Accessibility Overall** | √ | | √+ |
| 3.1 Document Design | √+ | | √+ |
| 3.2 Structure & Hierarchy | √ | | √ |
| 3.3 Summaries & Previews | √ | | √ |
| **4 Intercultural/Interpersonal Overall** | | | √+ |
| 4.1 Sensitivity to Audience | | √ | √+ |
| 4.2 Adapted to Culture/Situation | | | √ |
| **5 Usability Overall** | | √ | √ |
| 5.1 Content Fits Purpose | | √ | √+ |
| 5.2 Explanations Useful | | √ | √+ |

√ indicates significant improvements for seniors in one or more of the ANOVAs or Mann-Whitney U tests
√+ indicates the above plus significant improvements for sophomores in one or more of the Mann-Whitney U tests

For these reasons, it is impossible to determine the relative impact of each experience on student achievement. We can conclude, however, that taken together, the Cain Project, the curricular innovation, and course experience led to substantial improvements in students' skill as professional communicators.

In what follows, we discuss the general trends in the data and integrate the subjective impressions of the judges regarding the nature of the changes.

### Students Improved Dramatically in Oral Presentations

***Students' performance on oral presentations.*** Table 38 shows that the most dramatic impact of the Cain Project was the improved quality of bioengineers' oral presentations, particularly those created by seniors. As the data show, both sophomores and seniors made substantial gains on many of the key variables that benchmark quality in professional oral communication, but impressively, seniors improved across the variables.

Overall, seniors' oral presentations were outstanding—well orchestrated, technically fascinating, visually dramatic, ethically responsible, clear and persuasive. Moreover, most students exuded an ease and confidence in talking about their work, a confidence that was rare in the performances of sophomores. By the time students were seniors, they knew their subject matter well, had thought about it deeply, and were skilled in presenting a convincing account of their work. Students' oral presentations during the senior capstone course (BIOE 451/2) seemed to provide them with an opportunity to step back from their work and reflect on it. Seniors excelled in saying not only what they did and why they did it, but what it was good for.

In contrast sophomores had a tendency to focus on making certain their presentations were technically accurate and did so in a rather mechanical fashion, revealing some unease with the conventions of the professional discourse of bioengineering and with speaking in public (e.g., looked more at their slides than the audience). Sophomores tended to list their points in a pedantic fashion, sometimes losing focus in making their argument.

Quite a few sophomore presentations did not conclude well, failing to integrate the pieces of their talk. Some sophomores seemed unsure of how to shift their discourse to a more general level that might include "implications," "next steps," or an explanation of what the solution meant.

Despite these weaknesses, there was evidence that the Cain Project had a dramatic impact on the accessibility of sophomores' oral presentations. Between 2003 and 2005/6, sophomores' use of visual conventions and document design grew in sophistication as well as in consistency.

In addition to sophomores creating more accessible oral presentations, students also improved in their awareness of the audience, making strides in demonstrating their intercultural and interpersonal sensitivity. Generally speaking, sophomores' presentations were much more audience-oriented than the other genres they produced.

Sophomores also improved in making their presentations more usable; in particular, they were better at marshalling their content to fit the purpose and in making their explanations relevant to an audience's interests. It may be that as students were increasingly challenged to solve ill-structured problems—challenges posed by their immersion in problem-based learning in the BIOE 252 classroom—they acquired greater sensitivity to explaining their quantitative and engineering strategies. Overall, sophomores showed significant gains for oral presentations in 7 of 21 benchmarks of effective communication (see Table 38, page 61).

### Students Improved Moderately in Technical Reports and Posters

In contrast to their strong showing in oral presentations, students made modest improvements in the design of their technical reports and posters. As with oral presentations, seniors improved most.

***Students' performance on technical reports.*** By senior year, students had learned to make their reports accessible by using effective cues for document design (e.g., tables of contents, summaries, headers, footers, labels, captions, and so on). A related gain was in seniors' use of comprehensible visual conventions, particularly in the conventions for displaying quantitative data. This was quite an important improvement in the design of their technical reports because research shows that well-designed visual displays can enhance quantitative understanding and enable decision making—a goal that professional bioengineers strive to meet (Ancker, 2006; Elting et al., 1999).

The scarcity of significant improvements for persuasiveness in technical reports (see Table 38, page 61) may reflect a ceiling effect. Trends such as those in Figure 11 (see page 16 of this report) show that sophomores did well in articulating the strengths, limitations, and implications of their work and had little room to improve as seniors. (It would have been useful to know how well students performed on these aspects of report design prior to taking their sophomore course, but we do not have those data. We can assume, however, that these aspects of report design are not typically taught in high-school, making it more likely that sophomores' strong performance was a result of taking BIOE 252).

For the most part, sophomores tended to be quite literal in following the assignment for technical reports. Early in the Cain Project, assignments for technical reports prompted students with many short questions. The assignment became a kind of checklist and produced lengthy and often meandering documents. Students' literature reviews tended to be unintegrated lists of quotes from key references.

Early in the Cain Project sophomores wrote not for knowledgeable peers but for the teacher who had insider knowledge, and who could easily fill in the gaps of a loosely framed argument. As the Cain Project progressed, assignments took a more problem-based approach. This pedagogical change altered students' definition of their task and resulted in much improved literature reviews organized around the problems they wished to solve.

Many sophomore teams had difficulty applying visual conventions consistently. Some students pasted into their reports barely legible graphics without captions or bibliographic attributions. Some students displayed parts of the process or product they were studying in different sizes; instead, each should have been sized identically. Still others had excellent captions in one section and missing captions in the next. Problems such as these probably reflect a lack of coordination among team members during the writing and editing process. (These kinds of collaboration problems were for the most part solved by senior year.)

Sophomores demonstrated one significant advance in their technical reports: the "document design" of their projects. Sophomores grew better at signaling the content of their reports. Moreover, unlike students in the first cohort (2003), students in later cohorts almost always wrote shorter paragraphs organized as logical chunks, and included page numbers, headers, headings, and subheadings.

***Students' performance on posters.*** Results indicated that over successive years seniors grew more familiar with the genre conventions of technical posters, especially with segmenting content into logical groups in ways that audiences expected. Seniors' posters improved most in usability, offering content that matched the purpose—at the right level—while at the same time, providing useful explanations.

A deficiency in seniors' posters was that many needed better document design of their displays, especially the internal structure of each panel. Some students seemed unaware of the need to present information in an order that viewers would expect. There were additional problems with the flow of information, making it hard to know whether the posters were to be read by starting in the middle and working down or starting at the left column and working to the right.

Sophomores' posters were often difficult to comprehend because there were too few cues to enable viewers to make sense of the analyses and calculations. These deficiencies in signaling the quantitative content led to low scores on technical content and technical approach. That said, most sophomores' posters were reasonably organized and structured so that viewers could readily get a sense of the big picture.

### Why Greater Improvement on Oral Than Written Genres?

As we have seen, the results indicate that students improved most on oral presentations, which raises the question of why. Are oral genres easier than written ones? Was the instruction in oral presentations better than that for technical reports and posters? Did the timing of oral presentations (i.e., after the technical reports) allow students to integrate their evolving knowledge about their subject matter in ways that technical reports (which came first) did not? We surmise it was a constellation of all three.

Research on communication suggests that acts of communication, whether spoken or written, place significant demands—cognitive, social, and cultural—on the speaker or writer (Bazerman, 1983; Skinner, 1988; Torrance, 1999). When students are new to their discipline, communicating to experts in their field can be rather daunting (Bartholomae, 1985). Research suggests that novice communicators, regardless of domain, often experience frustration with delivering their messages in a clear and comprehensible way (Hayes & Bajzek, 2008; Schriver, 2007; Winsor, 1996). The literature also tells us that writing and speaking are not equivalent (Halliday, 1987; Tannen, 1984), with each presenting unique challenges, and which is easier depends on the capabilities and experience of the writer or speaker.

That said, when we speak we often get the benefit of social cues, people nod, give feedback, ask questions. But when we write, we must anticipate the audience's needs without their immediate presence. Thus writing is often more challenging than speaking because it asks us to imagine the social and cultural world in which our communication will be interpreted (Schriver, in preparation). Writing forces us to make explicit connections for readers that can be left implied when speaking. Still the social situation of speaking can make even seasoned professionals feel uneasy, making it more difficult than writing.

A different explanation of students' progress with oral presentations may have had to do with the level of detail teachers and the Cain Project staff provided in direct feedback. Although teachers and project staff created detailed assignments and provided exhaustive and helpful commentary on students' technical reports and posters, the comments on the oral presentations made more explicit the criteria for success (e.g., use diagrams that focus on critical elements), and this guidance may have been very helpful for students.

Another part of the answer as to why students did so well on oral presentation may have had to do with the sequencing of the three genres. Students completed their technical reports followed by either their poster presentation or their oral presentation, depending on the teacher's goals; but oral presentations were always assigned after the report. Consequently, by the time students created their oral presentations they had already thought through their subject matter (unlike the situation prior to creating their technical reports). The knowledge students developed through designing their technical reports may have enhanced their ability to step back from the details to summarize their work succinctly and persuasively in their oral presentations.

We surmise that the superiority of oral presentations was due to a combination of genre demands, excellent instruction, and sequencing.

## CONCLUSIONS

This research began with three questions:

Research question 1. Did bioengineering students improve in their professional communication skills from their sophomore to senior year? If so, in what ways and on which genres?

Research question 2a. Did both sophomores and seniors improve their professional communication skills over successive years with the Cain Project?

Research question 2b. Did the advantage of seniors over sophomores increase in successive years of the Cain Project? That is, did the added value of education in professional communication increase over time?

The answer to question 1, "did students improve from sophomore to senior year?" is "yes." Bioengineering students most certainly improved over time, and by their senior year, performed at a high level and with considerable skill across all three professional genres. Even those results that did not exhibit statistically significant improvements—for the most part—revealed gains, indicating a trend in a positive direction.

The answer to the second part of question 1, "on which genres did students improve?" is clear. Seniors made substantial improvements in delivering oral presentations, with gains in 20 of 21 measures (i.e., the grand mean overall, the 5 major variables, and 14 of 15 sub-variables). Seniors also made advances in the design of technical reports and posters, with significant improvements in about one-third of the 21 measures. Even when results were not significant, the trends were generally in the desired direction—toward improvement.

The answer to question 2a, "did both seniors and sophomores improve in successive years of the Cain Project?" is a qualified "yes." Seniors and sophomores did not improve at the same rate or with the same degree of success. As shown, sophomores got better on 7 of 21 measures for oral presentations and on 1 of 21 measures for technical reports. Juniors, however, did not improve significantly on posters. Because we do not know at what level students performed when they entered the sophomore class, we cannot gauge their growth from the freshman to sophomore year at Rice. We can see, however, that sophomores performed inconsistently and tended to get better on some aspects of professional communication while backsliding on others.

Sophomores' uneven performances underscore the difficulty of learning a new subject matter while at the same time acquiring skills in professional communication. The data also suggest that not all genres are equal and students need explicit education and continued practice in the discourse conventions of each.

The answer to question 2b, "did the Cain Project add value to students' educational experience at Rice over successive years of the project?" is "yes." As shown by Figures 5, 6, 7, and 8 (see pages 9-10 of this report), when the Cain project started, seniors performed at relatively the same level as sophomores. But as the Cain Project's teachers and staff developed increasingly sophisticated assignments, fine-tuned their criteria for student feedback, and developed explicit instruction in each genre, seniors developed in their ability to communicate as professionals. As these data make clear, senior cohorts showed gains midway through the Cain Project and they continued to progress, with their most dramatic gains in 2008. Each year of the Cain Project added value for seniors.

These data imply that education in professional writing and communication can make a lasting impact on students' ability to think in their discipline (as evidenced by students' improvement in "technical approach" in all three genres; see Figure 38, page 61). Moreover, education in professional communication enabled students to persuasively convey their technical knowledge and skill, regardless of genre.

The "bottom line" of this research is that seniors improved consistently and substantially over the course of the six-year period from 2003 to 2008—a testament to the merit of the Cain Project and to teaching excellence and curricular innovation in bioengineering at Rice.

## Implications

The results of this assessment of the Cain Project suggest that over time explicit instruction in writing and document design helps young engineers and scientists to develop their professional communication abilities in substantial ways. Sophomores—who were just learning to participate in their discipline—struggled with many aspects of professional writing, visual design, and oral presentation. They tended to be focused more on proving they had mastered the subject matter rather than identifying a problem and proposing a solution that would engage an audience.

By contrast, seniors' communication skills developed markedly. Across all three genres, seniors made significant improvements between 2003 and 2008. Seniors were less focused on showing their command of the subject matter and more directed towards persuading an audience of the adequacy of their approach to the problem and its solution. Students grew adept at making typical problems in bioengineering salient for difficult and often critical audiences, such as venture capitalists who might fund their research agendas.

The explicit teaching in professional communication, the problem-based learning, and the team-based approach to solving problems changed students' definition of their task (from a checklist of "must-do's" to a problem list of "must-solves"). The Cain Project encouraged young professionals to broaden their idea of communication and to strive toward making their bioengineering "moves" more transparent to an audience. Students seemed to shift their rhetorical stance from "reporter of someone else's knowledge" to "creator of their own knowledge."

Overall, the Cain Project helped students to become more effective professional communicators. Students learned not only how to think like a domain expert, but also how to communicate like one—moving flexibly from writing to speaking, from calculations to quantitative displays. Students mastered a number of the typical genres of their field, but also acquired a deeper understanding of how their field communicates its knowledge, intellectual products, and values.

As we have seen, this research shows that the Cain Project had the most impact on bioengineering students in their senior year. This finding reminds us that it takes time for the results of education in professional communication to influence student outcomes. There are two explanations for why this may be so. On one hand, it took several years for the impact of the instruction in professional communication to be realized because substantial institutional learning was required. The teachers needed time to develop, sequence, and fine-tune their assignments and feedback strategies in order to support students' growth. It seems evident that by the end of the Cain project the culture of the bioengineering program had changed in that engineering professors valued their influence on students' abilities to communicate like a professional. On the other hand, it seems evident that students' acquisition of knowledge, skill, and sensitivity in professional communication develops gradually over their college career. We would not necessarily expect sophomores to improve during their first year in a program, particularly since they were immersed in learning the subject matter of their discipline, learning to work in teams, and at the same time learning several genres in their field.

For these reasons, it is unlikely that one-shot attempts to improve engineering students' communication skills will be very effective. Indeed, if anything, this study shows the value of a multi-year commitment to communication-in-the-disciplines efforts, a commitment that extends across students' tenure in an academic program and that provides in-the-disciplines teachers with the time they need to integrate communication activities into their everyday teaching. In short, the study shows that to make a measurable impact on student performance requires institutional learning and cultural change.

## RECOMMENDATIONS

We strongly recommend that Rice continue its commitment to teaching professional communication in the engineering classroom. This study shows that for sustained improvement in the three genres studied here, engineering students require an even more extensive faculty commitment to professional communication. Moreover, bioengineering students of the future will need education in hybrid professional genres—such as those that mix text, graphics, photographs, quantitative displays, animations, video, and real-time data.

This assessment showed that while sophomores did improve on many important characteristics of professional communication, especially in the design of their oral presentations, it took until senior year to see the real impact of the Cain Project. From sophomore to senior year, students had two years of coursework in which they had opportunities to practice each genre roughly three to six times. Clearly teachers' attention to iterative design and detailed feedback paid off.

Since professional communication skills are centrally important to students' success in the academy and in the workplace, we recommend that Rice continue its efforts in assessing the impact of its engineering curricula on students' abilities. Particular projects that might be useful for tracking the development of students' growth as professional communicators include the following:

1. Collection of base-line data
    a. Base-line data from freshman and sophomore classes would facilitate assessment of skill changes when these students become juniors and seniors.
    b. Base-line data from all classes could facilitate the evaluation of curricular changes (e.g., the impact of problem-based learning). After instituting a change, instructors often find themselves wishing they had evaluated the previous year's class.
2. Student surveys
    a. Surveys of current students could identify aspects of instruction that students found most or least helpful.
3. Alumni surveys
    a. Surveys of alumni could identify instructional experiences that proved helpful on the job as well as gaps in their communications skills that alumni discovered after they joined the work force.
4. Employer and advisory board surveys
    a. Surveys of employers could reveal important characteristics of communication that are crucial to bioengineers in the workplace.
    b. Surveys of people who serve on advisory boards to programs in engineering could help assess, for example, students' oral presentations early and late in the program.
5. Longitudinal studies
    a. Although longitudinal studies are expensive, tracking a small sample of randomly selected students through the program can provide very useful information about the value added by the curriculum. Educational programs can learn a lot from a few well-documented cases.
6. Experimental studies
    a. Studies of students and their developing skills, for example, studies in which students who participate in particular curricular or pedagogical innovations are compared to students who participate in traditional courses.

    b. Studies of students whose engineering education is comprised of courses in which professional communication is an integral part of each course and those whose experience is comprised by more traditional engineering courses.

7. Cross-university studies
    a. Studies comparing educational practices and student performances across universities could provide the participating universities with new information about instructional procedures that work and fresh ideas about criteria for evaluating student performance. Such studies could help organizations such as ABET to operationalize their requirement that engineers graduate with an ability to "communicate effectively." Moreover, such studies could provide Rice with a benchmark for comparing the impact of its programs on students to those of other universities.

This assessment has shown that curricular innovations initiated by the Cain Project had a dramatic impact on student outcomes in professional communication at Rice. Continued and more sophisticated studies could guide and shape instruction so that students could reach even higher levels of performance.

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# Appendix A: Assessment Rubric
# A Study of Bioengineers as Professional Communicators Across Three Genres

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## Coding for Effectiveness in Professional Communication: Key Variables and Sub-variables

| | |
|---|---|
| **1 Comprehensibility** | Will readers/listeners understand the visual/verbal message?<br>Does it adhere to standards for clear writing/speaking?<br><br>1.1 Use of standard conventions for professional writing/speaking<br>1.2 Use of conventions for clear visual displays, charts, photographs<br>1.3 Adherence to conventions of genre/discipline<br>1.4 Adherence to standards for marshalling technical content |
| **2 Persuasiveness** | Will readers/listeners find the argument compelling?<br>Is there a credible articulation of the problem and its solution?<br><br>2.1 Cogent discussion of options/possible solutions<br>2.2 Credible articulation of technical argument/approach<br>2.3 Professional application of methods and computations<br>2.4 Demonstrated awareness of strengths, limitations, implications |
| **3 Accessibility** | Will readers readily grasp the organization and find what they want quickly? Can listeners anticipate what is coming next?<br><br>3.1 Document design is clear and purposeful<br>3.2 Structure reveals hierarchy of content<br>3.3 Summaries and previews integrate and interpret content |
| **4 Intercultural/ Interpersonal Effectiveness** | Will readers/listeners come away with an impression that the content is sensitive to their viewpoint and information needs?<br><br>4.1 Content shows sensitivity to the audience's expectations<br>4.2 Design choices are adapted to the culture and situation |
| **5 Usability** | Is the communication designed in ways that enable readers/listeners to use the content as they see fit?<br><br>5.1 Match between content and audience's purposes<br>5.2 Explanations make evident ways to use or assess content |

## Appendix A: Assessment Rubric for Judging Students' Professional Communications

### Five Characteristics of Written/Oral Communications Important for Effective Communication in Biochemical Engineering

### 1 Comprehensibility*

***Can the intended reader/listener understand the visual/verbal message?***

| | Score<br>Poor <-------> Excellent 1 | 2 | 3 | 4 | 5 | N/A | |
|---|---|---|---|---|---|---|---|
| 1. Use of standard conventions for professional writing/speaking | | | | | | | |
| 2. Use of conventions for clear visual displays, charts, photographs | | | | | | | |
| 3. Adherence to conventions of genre/discipline | | | | | | | |
| 4. Adherence to standards for marshalling technical content | | | | | | | |

### 2 Persuasiveness

***Will the reader/listener find the individual/team's argument compelling?***

| | Score<br>Poor <-------> Excellent 1 | 2 | 3 | 4 | 5 | N/A | |
|---|---|---|---|---|---|---|---|
| 1. Cogent discussion of options/possible solutions | | | | | | | |
| 2. Credible articulation of technical argument/approach | | | | | | | |
| 3. Professional application of methods, techniques, models, computations | | | | | | | |
| 4. Demonstrated awareness of strengths, limitations, implications | | | | | | | |

### 3 Accessibility

***Can readers find what they want quickly?***
***Can listeners anticipate what is coming next?***

| | Score<br>Poor <-------> Excellent 1 | 2 | 3 | 4 | 5 | N/A | |
|---|---|---|---|---|---|---|---|
| 1. Document design is clear and purposeful | | | | | | | |
| 2. Structure reveals hierarchy of content | | | | | | | |
| 3. Summaries and previews integrate and interpret key content | | | | | | | |

## 4 Intercultural and Interpersonal Effectiveness

***Will the audience come away with an impression that the individual/team is sensitive to their information needs and expectations?***
***Is the communication responsive to the audience's culture and situation?***

**Score**
**Poor <-------> Excellent**

| | 1 | 2 | 3 | 4 | 5 | N/A | |
|---|---|---|---|---|---|---|---|
| 1. Demonstration of sensitivity to stakeholders' needs/expectations | | | | | | | |
| 2. Adaptation to readers'/listeners' culture and situation | | | | | | | |

## 5 Usability

***Does the content fit readers'/listeners' purposes for engagement?***
***Can the audience take appropriate action upon reading/listening?***

**Score**
**Poor <-------> Excellent**

| | 1 | 2 | 3 | 4 | 5 | N/A | |
|---|---|---|---|---|---|---|---|
| 1. Match between content and audience's purposes | | | | | | | |
| 2. Explanations make evident ways to use or assess content | | | | | | | |

# Appendix B: Detailed Assessment Rubric for Judging Professional Communications

## Five Characteristics of Written/Oral Communications Important for Effective Communication in Biochemical Engineering

### 1 Comprehensibility*

***Can the intended reader/listener understand the visual/verbal message?***

**Score**
**Poor <-------> Excellent**

| Indicators/Evidence: | 1 | 2 | 3 | 4 | 5 | N/A |
|---|---|---|---|---|---|---|
| 1. Use of standard conventions for professional writing/speaking | | | | | | |
| • Style and syntax adapted to readers** | | | | | | |
| • Grammar and punctuation follow conventions of written/spoken English | | | | | | |
| • Organization and structure are logical | | | | | | |
| • Technical terms defined in relation to audience's knowledge | | | | | | |
| | | | | | | |
| 2. Use of conventions for clear visual displays, charts, graphs, photographs | | | | | | |
| • Point-driven graphs, charts, and tables | | | | | | |
| • Explanatory captions and legends | | | | | | |
| • Consistent use of labels, scales, units, and axes | | | | | | |
| • Simple photos, diagrams, illustrations presented before complex ones | | | | | | |
| • Main points in focus; excessive detail omitted | | | | | | |
| | | | | | | |
| 3. Adherence to conventions of genre/discipline | | | | | | |
| • Engaging framing of problem, objective, or overview | | | | | | |
| • Effective use of mathematical/statistical symbols/conventions | | | | | | |
| • Sections organized according to genre/disciplinary conventions | | | | | | |
| • Amount of elaboration follows conventions/requirements for length | | | | | | |
| | | | | | | |
| 4. Adherence to standards for marshalling technical content | | | | | | |
| • Clear statement of research methods/design approach | | | | | | |
| • Appropriate explanation of data collection techniques | | | | | | |
| • Lucid explanation of how measurements were made | | | | | | |
| • Correct calculations and analyses | | | | | | |
| | | | | | | |

**Note:** * Numbered items (1-5) and their enumerated subpoints are the characteristics we coded for.
** Itemized subpoints werer provided as reminders to anchor raters' evaluations.

## 2 Persuasiveness

***Will the reader/listener find the individual/team's argument compelling?***

**Score**

**Poor <-------> Excellent**

| Indicators/Evidence: | 1 | 2 | 3 | 4 | 5 | N/A |
|---|---|---|---|---|---|---|
| 1. Cogent discussion of options/possible solutions | | | | | | |
| • Awareness of previous research/design solutions | | | | | | |
| • Criteria for evaluating solutions presented | | | | | | |
| • Feasibility of recommended solution addressed | | | | | | |
| • Sustainability of proposed solution described | | | | | | |
| • Comparative advantages over competition elaborated | | | | | | |
| | | | | | | |
| 2. Credible articulation of technical argument/approach | | | | | | |
| • Well chosen technical approach | | | | | | |
| • Clear explanation of the principles behind the decisions | | | | | | |
| • Cogent statement of assumptions | | | | | | |
| • Coherent flow of reasoning; no gaps in logic | | | | | | |
| | | | | | | |
| 3. Professional application of methods, techniques, models, computations | | | | | | |
| • Sound strategy for calculations and computations | | | | | | |
| • Easily understood articulation of models and theories | | | | | | |
| • Methods/techniques well suited to problem/purpose | | | | | | |
| • Sufficient detail to support claims/main point | | | | | | |
| | | | | | | |
| 4. Demonstrated awareness of strengths, limitations, implications | | | | | | |
| • Strengths of approach/strategy/solution articulated explicitly | | | | | | |
| • Limitations of approach/strategy/solution recognized | | | | | | |
| • Implications for future work discussed (e.g., marketing, research) | | | | | | |
| | | | | | | |

## 3 Accessibility

***Can readers find what they want quickly?***
***Can listeners anticipate what is coming next?***

**Score**
**Poor <-------> Excellent**

| 1 | 2 | 3 | 4 | 5 | N/A |
|---|---|---|---|---|---|
| | | | | | |

Indicators/Evidence:

1. Document design is audience-oriented and purposeful
   - Coherent pattern of organization
   - Purpose-driven headings and subheadings
   - Main points summarized/highlighted visually
   - Visual design consistent, functional, aesthetically pleasing

2. Structure reveals hierarchy of content
   - Well chosen visual and typographic cues signal structure
   - Main points are separate from supporting details (in appendices)
   - Conclusions integrate main points/findings in relation to objectives

3. Summaries and previews integrate and interpret key content
   - Summary statements/figures reveal overall findings/big picture
   - Previews forecast what comes next or what to notice (e.g., in graphs)
   - Tables, graphs, or drawings highlight trends, relationships, main points

## 4 Intercultural and Interpersonal Effectiveness

***Will the audience come away with an impression that the individual/team is sensitive to their information needs and expectations?***
***Is the communication responsive to the audience's culture and situation?***

**Score**
**Poor <-------> Excellent**

| 1 | 2 | 3 | 4 | 5 | N/A |
|---|---|---|---|---|---|
| | | | | | |

Indicators/Evidence:

1. Demonstration of sensitivity to stakeholders' needs/expectations
   - Connects to audience's knowledge, values, beliefs, or assumptions
   - Reveals respect for audience through level of complexity
   - Avoids jargon, idioms, metaphors that may confuse
   - Responds to audience's questions with skill (e.g., in oral presentations)
   - Reveals a sense of human-centered values and ethics through choices and explanations

## 4 Intercultural and Interpersonal Effectiveness (continued)

***Is the communication responsive to the audience's culture and situation?***

Indicators/Evidence:

2. Adaptation to readers'/listeners' culture and situation
    - Links between project features and audience's values made explicit
    - Delivers content in a way that engages the audience
    - Projects persona that reveals sensitivity to the culture
    - Shows cultural awareness by choices in visual/verbal design

**Score**

**Poor <-------> Excellent**

| 1 | 2 | 3 | 4 | 5 | N/A |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

## 5 Usability

***Does the content fit readers'/listeners' purposes for engagement?***
***Can the audience take appropriate action upon reading/listening?***

Indicators/Evidence:

1. Match between content and audience's purposes
    - Structures content with audience's purposes for reading/listening in mind
    - Offers context/advice/procedures for evaluating results
    - Provides information for taking action (e.g., regulations, codes)

2. Explanations make evident ways to use or assess content
    - Processes described in a manner that allows for replication
    - Appendices sufficiently detailed to allow for rechecking of calculations
    - Next steps/considerations discussed from audience's perspective

**Score**

**Poor <-------> Excellent**

| 1 | 2 | 3 | 4 | 5 | N/A |
|---|---|---|---|---|---|
| | | | | | |
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