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ABSTRACT

The "HumEn" (Humanities/Engineering Integration) program developed at the Colorado School of Mines integrates humanities and engineering through reading and writing. Through integrative reading and writing engineering students are led to make appropriate connections between the humanities and their technical work, connections that will carry over into their professional lives. A thematic approach links an introductory chemical engineering course with a humanities course and examines such issues as: the methods used by scientists, engineers and humanists; the world view necessary to produce science and technology; the value trade-offs inherent in a technological society; and the technical questions faced by engineering professionals. The course emphasizes class discussion, open-ended design projects, teamwork, and a variety of writing assignments, including a semester-long journal. Students involved in HumEn courses find the experience both rewarding and broadening, based on data collected over 5 years. Engineering students are interested in the questions raised by the humanities and they particularly appreciate an opportunity to read and write about literature, history, philosophy, and drama in the context of their engineering discourse community. (The HumEn Integrated Course syllabus and four figures of data are included.) (RS)

A Model for Professional Education in the 21st Century: Integrating Humanities and Engineering Through Writing

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"Literary intellectuals at one pole--at the other scientists, and as the most representative, the physical scientists. Between the two a gulf of mutual incomprehension--sometimes (particularly among the young) hostility and dislike, but most of all lack of understanding. They have a curious distorted image of each other. Their attitudes are so different that, even on the level of emotion, they can't find much common ground" (Snow 4).

Introduction

Even though it has been nearly 35 years since C. P. Snow delivered the Rede lecture which he titled The Two Cultures, as we move towards the 21st century we seem no closer to bridging the gap between the scientific and humanistic communities than we were in 1959. If anything, knowledge has become more fragmented and specialized since then. In most universities departmental fiefdoms assure that disciplinary purity is maintained, and higher education continues to be packaged in discrete units called courses. As one response to the "two cultures problem," we have developed a course which integrates humanities and engineering through reading and writing. Although we acknowledge that scientists, engineers, and humanists live and function in different discourse communities, we also believe that some connections among these communities must be made if we are to avoid a 21st century Tower of Babel. We believe that our course provides a model which could be extended to produce a truly integrated professional education for the next century.

All students should be exposed to connections among the disciplines that they study, and we believe the most effective exposure comes through integrative reading and writing. We are not arguing for doing away with the traditional disciplines; we are arguing for making the separations between them more transparent and porous. At key points in our students' education, they should be exposed to truly interdisciplinary approaches to larger issues. We have developed one such approach at the Colorado School of Mines (CSM) with help from the National Endowment for the Humanities (Olds and Miller, Miller and Olds). We call the program HumEn (Humanities/ Engineering Integration). In our HumEn course, we link an introductory chemical engineering course with a humanities course and examine such issues as the methods used by scientists, engineers, and humanists; the world view necessary to produce science and technology; the value trade-offs inherent in a technological society; and the ethical questions faced by engineering professionals. Course readings and films include Shelley's Frankenstein, Conrad's Heart of Darkness, Descartes' Discourse on Method, Brecht's Galileo, and Else's The Day After Trinity. Both professors in the course (a humanist and an engineer) are involved in exploring these issues in the context of our students' engineering culture. Instead of the traditional lecture format, our course emphasizes class discussion, open-ended design projects, teamwork, and a variety of writing assignments, including a semester-long journal.

Based on data we have collected over the past five years, we believe that students involved in HumEn courses find the experience both rewarding and broadening. They believe that they gain insight into the importance of the humanities in their lives through the reading and writing that they do in HumEn courses. We have concluded that, contrary to popular myth, engineering students *are* interested in the questions raised by the humanities and that they particularly appreciate an opportunity to read and write about literature, history, philosophy, and drama in

the context of their engineering discourse community. Perhaps our program demonstrates on a small scale what professional education in the 21st century might look like.

Engineering Education

In recent years engineers have been criticized for not adequately considering the human and social implications of their actions; as a result engineering educators are increasingly expected to produce baccalaureate engineers who are well-versed in humanities and social sciences. However, intense pressure to maintain, if not expand, technical requirements within engineering curricula all but eliminates any chance to offer more humanities courses. In addition, the guidelines from ABET (Accreditation Board for Engineering and Technology), the accrediting agency for engineering, mandate that engineering students take only the equivalent of one semester's classes in the humanities and social sciences (H&SS) (ABET 6). At CSM, for example, our students are required to take 18 semester credit hours in H&SS, generally 6 courses, out of a total of 136-144 credits! Six of those hours are satisfied with a required introductory H&SS course and a required economics course. In the remaining twelve hours, students must obtain both "breadth" and "depth" according to the ABET guidelines (7). In reality, students take a cafeteria approach to their H&SS requirements and often graduate with little sense of the importance of the humanities to their profession or to their lives.

In addition, there is currently almost no explicit connection between the technical and H&SS sides of an engineering student's education. We see at least two approaches which offer partial solutions to the students' dilemma:

- Do a better job of helping students choose H&SS electives so that they pursue a coherent, logical progression of courses;

- Better integrate the study of liberal arts into existing technical courses.

The recent Association of American Colleges report, Unfinished Design--The Humanities and Social Sciences in Undergraduate Engineering Education (Johnston, et al.), offers suggestions for implementing the first approach by planning more coherent, integrated humanities offerings and improving academic advising. At CSM we are pursuing the second approach through the HumEn program which seeks to help engineering students make appropriate connections between the humanities and their technical work, connections that will carry over into their professional lives.

We believe with Alfred North Whitehead that "the antithesis between a technical and a liberal education is fallacious. There can be no adequate technical education which is not liberal, and no liberal education which is not technical; that is, no education which does not impart both technique and intellectual vision" (48). The real question is how to meaningfully achieve such integration of liberal and technical education given the existing curricular, financial, and political constraints at most colleges and universities.

The "Engineering Culture" vs. Engineering Education

There is a great deal of evidence to support the idea that, although engineering education is changing, it often bears little resemblance to engineering practice. For example, most engineering science classes still rely on the traditional "three-cubed" method: three lectures per week, three homework problems per class, and three tests per semester. Course content is usually computational and objective; little or no attempt is made to introduce students to any facets of engineering practice beyond "number crunching." In this mode students come to believe that all questions have right or wrong answers which can be found at the back of the book. There is considerable evidence that this practice is driving students away from engineering, students who could be productive, successful practicing engineers (Green, Hewitt and Seymour, Tobias).

In contrast to the way in which most engineering courses are taught, practicing engineers must deal constantly with uncertainty and ambiguity. Among the tools needed by practicing engineers are:

- computational and analytical skills
- technical knowledge
- the ability to synthesize and design
- integrative thinking skills
- interpersonal skills
- critical thinking skills
- breadth of knowledge
- ethics
- humane values

In designing our HumEn curriculum we worked from the premise that our students must discover that engineering is much more than calculations and formulas, that engineering is a human enterprise, and that humanistic and other considerations affect all "real-world" engineering projects.

The HumEn Course

In planning our new course, we wanted not only to include a healthy dose of humanities, but also to change substantially the course format to make both technical and humanistic studies more integrated and enjoyable. Our changes included:

- emphasizing class discussion rather than lecture
- assigning less rote homework and more open-ended design problems with both technical and non-technical constraints
- working frequently in small groups rather than individually
- requiring more reading, writing (including a journal), and speaking
- explicitly discussing connections between the technical and H&SS aspects of course material whenever appropriate

Our program links two courses, CR 301 (Chemical Process Principles), the first required course for chemical engineering majors at CSM, and HU 396 (Special Topics in Humanities). Students must enroll in both courses in order to participate in the program. They receive six semester

hours of credit and they satisfy both a chemical engineering requirement and an H&SS general requirement for a mid-level elective. The chemical engineering course (which is also offered each semester in a non-HumEn format) is a traditional sophomore-level introduction to the application of mass and energy conservation principles to chemical processes. A course syllabus for the six-credit HumEn course is summarized in Table I.

Table I
HumEn Integrated Course Syllabus

Introduction: The Culture of Chemical Engineering Practice; F & R, chapter 1,"What Chemical Engineers Sometimes Do for a Living"; course introduction; introduce use of journals.

Snow, Two Cultures; F & R, chapter 2, "Introduction to Engineering Calculations."

Personal and Professional Ethics; Pirsig, Zen and the Art of Motorcycle Maintenance, part I; Else, The Day After Trinity (video); F & R, chapter 3, "Processes and Process Variables."

Brecht, Galileo; professional code of ethics; whistle-blowing case studies; F & R, chapter 4, "Fundamentals of Material Balances."

Stewardship and Approaches to Issues of Human Dignity; Hardin, "The Tragedy of the Commons"; Zen, part II; design project #1; continue with F & R, chapter 4.

Belenky, et al., excerpts from Women's Ways of Knowing; Shakespeare, MacBeth; finish F & R, chapter 4.

White, "The Historical Roots of Our Ecological Crisis"; F & R, chapter 5, "Single Phase Systems"; presentation of design project #1 solutions.

Technological Power: Its Opportunities and Dangers; Goodman, "Can Technology Be Humane?"; F & R, chapter 6, "Multiphase Systems."

Zen, part III; finish F & R, chapter 6.

Shelley, Frankenstein; F & R, chapter 7, "Introduction to Energy Balances" introduce design project #2.

Technology and Cultural Imperialism; Peng, "Underdeveloping the Third World"; Coppola, Apocalypse Now (film); F & R, chapter 8, "Balances on Non-Reactive Processes"; continue design project #2.

Conrad, Heart of Darkness; continue F & R, chapter 8; exam #2.

Zen, part IV; F & R, chapter 9, "Balances on Reactive Processes"; presentation of design project #2 solutions.

Method in Engineering, Science, and the Humanities; Descartes, excerpts from Discourse on Method; Koen, excerpts from The Engineering Method; finish F & R, chapter 9.

Critical readings from Frankenstein; F & R, chapter 11, "Balances on Transient Processes."

note: F & R = Elementary Principles of Chemical Processes, Felder and Rousseau, 2nd edition, Wiley, 1986.

The amount of technical material covered in HumEn is the same as in the traditional course, although the HumEn course utilizes design projects and cooperative learning exercises in addition to standard homework assignments to introduce and reinforce some concepts. The course is organized using a thematic approach to broad questions of importance to our engineering students. Although the themes vary somewhat from year to year, the following ones have been explored consistently:

- Personal and professional ethics
- Stewardship and human dignity
- Technological power: opportunities and dangers
- Technology and cultural imperialism
- Method in science, engineering, and humanities

The following example will serve to show how a theme is incorporated into the integrated course. Early in the semester we present the students with two "problems" to "solve"--a mass balance question from their text which they do not yet have the technical knowledge to solve and a difficult poem which we ask them to analyze and critique. At this point we briefly discuss method, asking them what they need to know in order to attack these two problems. They see early on that although a chemical engineering problem and a poem are not similar in every way, there are some common areas that link them. For example, in both cases the students would like more factual knowledge than they are given, they would like more background information, and they would like to know the "givens" of the problem, e.g, what is the basic formula for finding mass balances? or what is the usual form for a sonnet? After this introduction we return to the question of method throughout the semester, concentrating especially on the methods of the scientist, the engineer, and the literary critic and why it is important to understand the similarities and differences among them.

Our students are most familiar with the scientific method (or at least the cookbook version of it they have often been taught in their lab science courses), so we generally start our discussion with it. Readings that we use which bear on this method include Brecht's Galileo, Pirsig's Zen and the Art of Motorcycle Maintenance, and Descartes' Discourse on Method. In brief, we

examine the generally lockstep but iterative approach of the scientist and the goal of science, which is to find THE Truth.

In contrast, we then explore the engineering method, which Billy Koen defines as "the strategy for causing the best change in a poorly understood or uncertain situation within the available resources" (Koen 5). In this context we evaluate Victor Frankenstein's doomed experiment in Shelley's Frankenstein and discuss whether Victor is acting as a scientist or an engineer. We also assign two design projects during the semester which the students work on in teams. These projects, unlike typical homework problems, involve complex questions to which several alternative solutions are possible. In a recent project the teams were asked to consider the issue of acid rain from two viewpoints--technical and social. Their technical analysis consisted of performing mass and energy balances for a 500 megawatt coal-fired power plant and computing the amount of sulfur dioxide released to the atmosphere. They also completed mass and energy balances and a simple economic analysis for two options to control SO_2 emissions: physical coal cleaning and limestone injection. From these results, they were able to estimate the incremental costs of controlling acid rain using these two technologies, and they began to appreciate the economic realities of pollution control--yes, a clean environment is certainly desirable, but it's frequently difficult to achieve and often prohibitively expensive. In working on such a project, it quickly became obvious that engineering is not a "value free" profession.

Finally, we discuss the methods applied by literary critics, most recently using the Bedford edition of Frankenstein as our text because it includes brief introductions to various critical schools as well as sample critical essays. This part of the course helps our engineering students realize the complexity of modern literary criticism; they come to recognize that criticism in not simply "what I like," but instead is a rich and complex intellectual pursuit on a par with science or engineering. Through our semester-long exploration of method, students learn not only that different communities take different approaches to problem-solving, but that in some ways these approaches are related. For example, they often discover that in both engineering and literary criticism, there is no one "right" answer, but that there are components of their analysis that are correct or incorrect, e.g. a mass balance can only be done correctly or incorrectly, but it can be applied in many ways; a poem can "mean" many things, but a sonnet has only a certain number of generally acceptable forms.

Writing in HumEn

Writing is the glue which binds the HumEn curriculum. Over their semester in the class students write in a variety of formats about the technical material in the course, the readings, the class itself, and their efforts at integrating ideas. The integrated class replaces a chemical engineering course in which no written assignments are traditionally given. In fact, one of the problems in much engineering education is that, with the exception of the design classes usually offered during the senior year, students are required to do little writing. HumEn students, in contrast, do a great deal of writing and speaking in the following assignments:

- Formal papers related to course readings and class discussions
- Essay questions on exams
- Reports on design projects
- Journals

Last year's students were asked to write two short papers (4 or 5 pages), one a traditional response essay and the other a review and comparison of Conrad's Heart of Darkness with Coppola's Apocalypse Now. For the response essay, students were given a choice of several open-ended topics, including this one:

> Explore the conflicts between the individual scientist/engineer and authority in several of the works we have read/seen so far this semester. Possible examples include Galileo/ the Church, Oppenheimer/ General Groves, Boisjoly/ his managers. What causes these conflicts? How are such conflicts resolved? What role does ethics play in their resolution?

Students are also asked to respond to questions on the exams. Usually course exams are scheduled in three hour blocks, with the expectation that most students will finish in approximately two hours. The exams include both technical questions and humanities questions. An example of an essay question would be:

> As he is dying, Victor Frankenstein says to Walton, "Seek happiness in tranquillity, and avoid ambition, even if it be only the apparently innocent one of distinguishing yourself in sciences and discoveries." Select two or more of the protagonists in works we have read this semester and discuss what their reactions to Victor's advice might have been.

For their design projects the students are asked to report the results of their team's work in a short report to the professors and their classmates. In addition to selecting and justifying an "optimal" solution to the problem, they are asked to "List at least 5 additional constraints on the process and discuss the effect of each on your 'optimal' solution. At least two of these constraints should be non-technical ones. How would you address these constraints in your proposed process design?"

In their journals (which are collected four times during the semester, responded to, and graded holistically at the end of the semester), students are sometimes given specific topics to reflect on from the course readings and technical materials. They are also given free reign to reflect on class discussions, readings, exams, professors and fellow students. We obtain a great deal of very valuable feedback from the journals. Journals are a place where students make their own connections between the engineering and humanities parts of the course. Some excerpts from student journals may help to illustrate the kinds of thinking the students are doing, in this case related to Frankenstein:

> In Frankenstein, I believe Mary Shelley is not making a statement along the lines of "technology and scientific advancement is just plain awful and we as a society should make a move backward." Instead, I think that she makes a strong argument on the side of bringing a sense of responsibility and forethought to the scientific world. She is not

against advancement and knowledge. Instead she appears to be in favor of it. She only cautions against using one's knowledge and not taking responsibility for it.

-- Teresa Spelts

Sometime I acquire the mindless, obsessive drive that Victor does. Well, maybe not quite as bad, but in trying to get everything done for classes, I tend to become a bit of an obsessive hermit--shutting out all parts of life other than academic. If it weren't for track practice, I would probably go crazy. I would say that Shelley does a very good job of depicting obsessive, driven behavior and its destructive effects in Frankenstein.

-- Andrew Espenscheid

Evaluation of the HumEn Program

From the beginning we have used various methods, quantitative and qualitative, summative and formative, to evaluate the HumEn program. We have used the information we gathered through evaluation to improve the course and to demonstrate to our faculty peers and the National Endowment for the Humanities that we are indeed achieving our goals.

Student evaluations. For the past five years HumEn students have been asked to fill out surveys at the beginning and end of the semester. These surveys were designed to measure students' perceptions about the importance of humanities to their education and profession. Three statements from the survey help to illustrate the impact the HumEn course has on our students:

1. Humanities won't enhance my engineering career.
2. Humanities are important to my engineering education.
3. Engineers are only responsible for technical solutions. Others are responsible for any non-technical ramifications of their actions.

Survey statement #1 was designed to determine if the students can evaluate the importance of humanistic studies beyond what they are required to take during college. As shown in Figure 1, about 75% of our HumEn students at the beginning of the semester disagreed or strongly disagreed with the statement that "humanities won't enhance my engineering career" while nearly 96% disagreed or strongly disagreed by the end of the course. Opinions of non-HumEn students enrolled in traditional sections of CR 301 remained much more constant with 68% disagreeing or strongly disagreeing at the beginning of the course and 76% disagreeing or strongly disagreeing at the end.

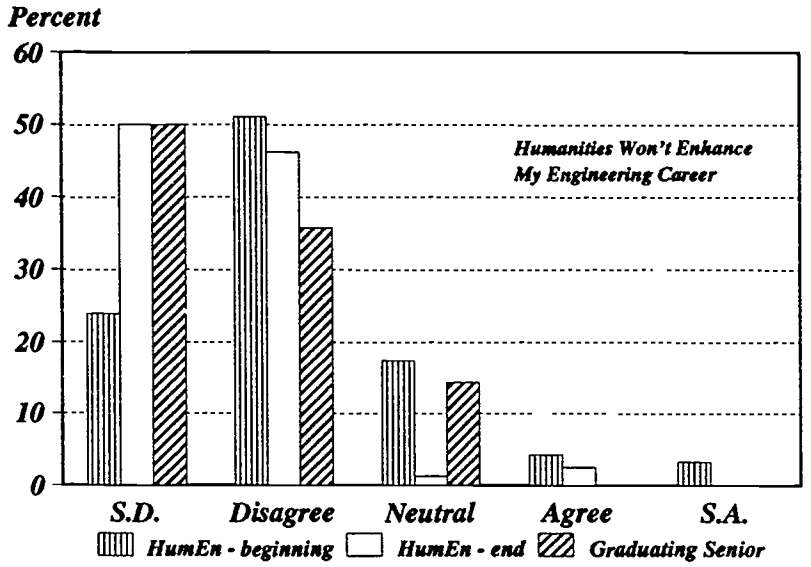

Figure 1 - HumEn Student Responses to Survey Statement #1
(S.D. = strongly disagree; S.A. = strongly agree)

Similar trends were noted for survey statement #2 which was designed to measure whether students think humanities studies are valuable to them during their college careers. Figure 2 summarizes the survey results, which once again show that HumEn students have a stronger appreciation for humanities by the end of their HumEn experience. For example, at the beginning of the semester only 28% of the HumEn students strongly agreed with the statement that "humanities are important to my engineering education." By the end of the semester 56% strongly agreed and nearly 96% agreed or strongly agreed. Once again, much less change in student perceptions was noted in the non-HumEn control group.

Finally, survey statement #3 probes the students' understanding of their responsibilities for the non-technical (environmental, political, ethical, etc.) aspects of their work. Results from this survey statement are shown in Figure 3. By the end of the course, nearly 75% of the HumEn students strongly disagreed with the statement that "engineers are only responsible for technical solutions...others are responsible for any non-technical ramifications of their actions" while only 50% strongly disagreed at the beginning of the course. About 50% of the non-HumEn control group strongly disagreed with this statement, a percentage which remained nearly constant from beginning to end of the semester.

Taken together, the results obtained in this survey suggest that the HumEn course does influence the perceptions of students in the course to a much greater extent than in the traditional non-integrated version. While not a statistically valid survey of engineering students as a whole, these results clearly show that attitudes of the HumEn students are significantly improved compared with other sophomore-level chemical engineering students at CSM.

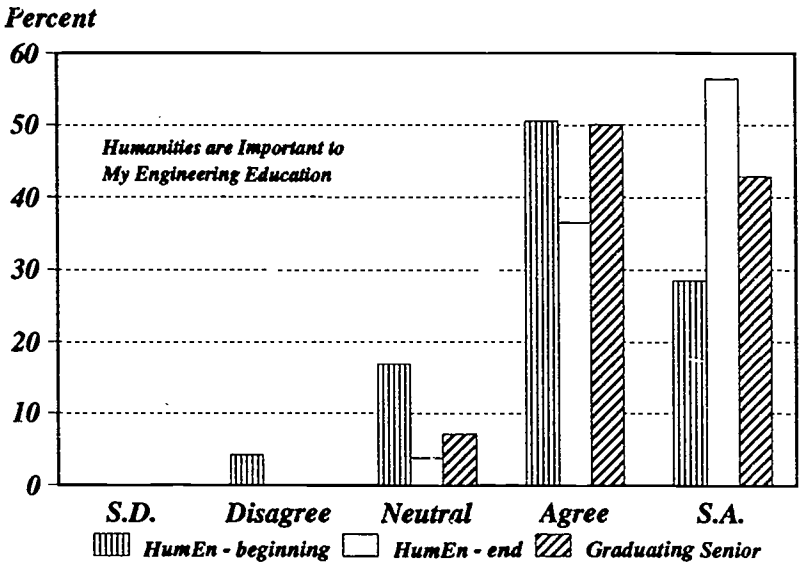

Figure 2 - HumEn Student Responses to Survey Statement #2
(S.D. = strongly disagree; S.A. = strongly agree)

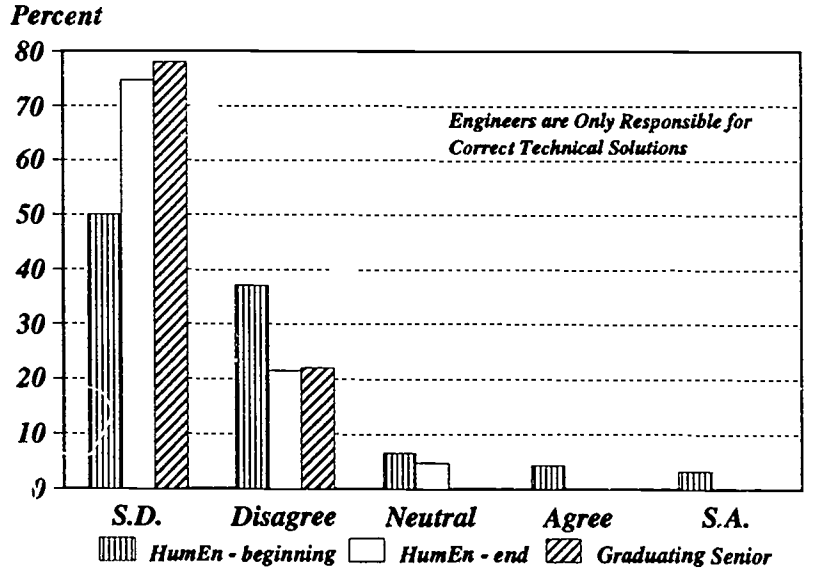

Figure 3 - HumEn Student Responses to Survey Statement #3
(S.D. = strongly disagree; S.A. = strongly agree)

Do the attitudinal changes we observe in our sophomore HumEn students stay with them after the course has ended? In a followup survey of graduating seniors we found that HumEn alumni retained their attitudes about the importance of humanities as indicated in Figures 1-3. In fact, 100% of the seniors either disagreed or disagreed strongly with the statement that "engineers are only responsible for technical solutions."

Student satisfaction with the course is also consistently high. When evaluated using a campus-wide instrument, the course instructors are ranked among the highest in both the Chemical Engineering and Liberal Arts and International Studies Departments. We also collect data each year about student satisfaction with technical content, humanities content, integration of the two, and group work. The cumulative results are reported in Figure 4. Clearly, student satisfaction is high.

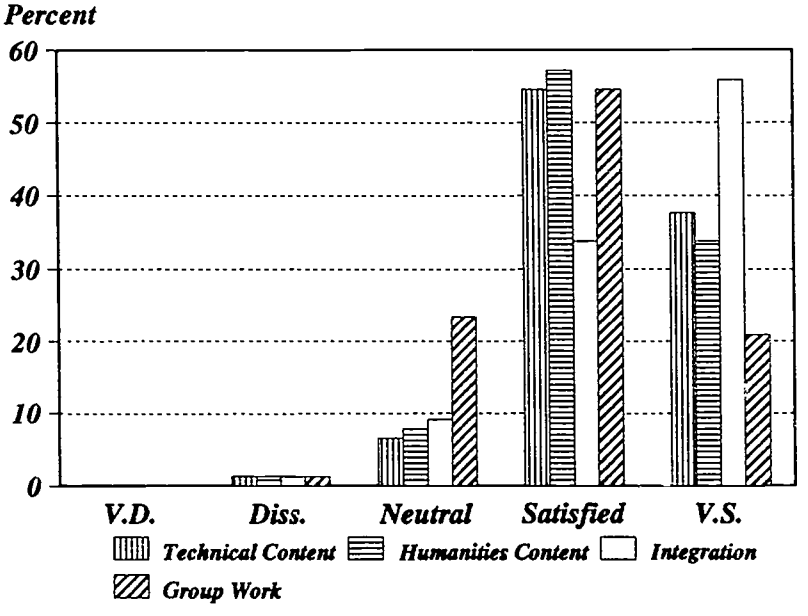

Figure 4 - Results of HumEn Student Satisfaction Survey
(V.D. = very dissatisfied; V.S. = very satisfied)

Finally, we have a great deal of anecdotal evidence that students appreciate the learning they have done in the course. The following quotes from student journals illustrate the types of comments we frequently get:

> I wanted to let both of you know how much I enjoy this class. It's nice to actually know my professors and to know that they care where this class and this school is taking me. I've only missed one [HumEn] class this semester and when I did I felt like a bum and I was kind of regretful because you never know what is going to happen in that classroom. It's not like it's some big event I plan; after all, it's simply a course I have to take, but I must say that it is the most enjoyable and fulfilling class I've had at Mines.
>
> -- Jessie Verizzo

There were times when this class made me doubt whether I would be a good engineer or not. I hope that I will never have to deal with crooked company ethics. At this time, I do not know all of the constraints which would affect my decision as to what I should do given a situation like Boisjoly's [Challenger disaster]. What scares me about engineering is having to make a decision that actually affects people's lives. I don't know if I ever want to have that much responsibility. At least, when it comes time to make a critical decision I will have some background and knowledge of case histories from this class to consider.

-- Anonymous Student

In addition to gaining positive perceptions about the importance of humanities to engineers, HumEn students perform better than control students on examinations which are judged by departmental faculty to be of equivalent difficulty. These results cannot be explained solely on the basis of differences in student abilities, since the HumEn students' cumulative GPA of 2.91 is only marginally better than the control group's 2.75.

Consultants' evaluation. As part of the project work funded by the National Endowment for the Humanities, two distinguished consultants provided us with an independent evaluation of HumEn. Dr. John Prados, Professor of Chemical Engineering and Vice-president Emeritus of the University of Tennessee, and Dr. Richard Olson, Professor of History from Harvey Mudd College, visited with HumEn students and faculty, campus administrators, and members of the HumEn campus advisory committee. Their overall impression of the program was very favorable, as the comments below from their project evaluation indicate:

"The HumEn pilot course has been highly successful in engaging the interest of engineering students and helping them understand the positive contribution that study in the humanities can make to their professional education."

"[The course] seems to be creating more favorable attitudes toward humanities and social sciences in general as well as greater awareness of non-technical criteria for making engineering design choices, while it seems to leave technical performance not only unimpeded but even improved."

"The design projects are seen as an effective way of bringing together the technical and humanistic aspects of the course."

Conclusion

Our observations of our students and their learning over the past five years have led us to the following conclusions regarding students in HumEn courses:

- They perform at least as well in their technical work as other students in the introductory chemical engineering course.
- They gain a better understanding of the importance of humanities in engineering.

- They demonstrate the ability to make numerous connections between their technical and humanities studies.
- They exhibit more enthusiasm about their discipline than other students.
- They recommend that at least one HumEn course be required of all students at CSM.
- They have more opportunities than their counterparts to write and speak in a technical course.

Based on our experiences, we believe that courses like HumEn could serve as a powerful bridge between the two cultures and a model for 21st century professional education.

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