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ABSTRACT

This project was designed to develop a curricular and pedagogical model for teaching multidisciplinary engineering design to senior-level undergraduate students at the Colorado School of Mines. The two-semester course sequence involved students from seven engineering disciplines working in multidisciplinary teams under the direction of engineering, science, and liberal arts faculty to complete design projects for clients from industry and government. The course was designed to help student creatively solve open-ended "real" problems; learn to use a multidisciplinary approach that simulates actual industrial experience; work with others in small design teams; appreciate and consider nontechnical constraints; develop client relations; learn to conduct independent research; and enhance oral and written communication skills. Two pilot projects were successfully completed, with students, faculty, and clients all rating the program favorably. Included are project descriptions, evaluations, and follow-up plans, as well as a list of presentations and publications disseminating project information. Appended are an industrial design questionnaire and summary of survey results; course syllabi; client letters for projects and executive summaries; student recruiting flyer; student perception questionnaire and summary of survey results; course, peer, and self-evaluation questionnaires and summary of survey results; client evaluation form and summary of results; and articles publicizing the program. (Contains 27 references.) (JLS)

Project Title: A Multidisciplinary Model for Teaching Undergraduate Engineering Design

Cover Sheet

Grantee Organization:

Colorado School of Mines
1500 Illinois Street
Golden, CO 80401

Grant Number:

P116B91034

Project Dates:

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Ending Date: August 31, 1992
Number of Months: 36

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	Year 1	$ 67,303
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	Year 3	$ 61,400
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Summary Paragraph

In this project, we have developed a curricular and pedagogical model for teaching multidisciplinary design to senior engineering students at the Colorado School of Mines. In our course sequence, students from seven engineering disciplines work in multidisciplinary teams under the direction of engineering, science, and liberal arts faculty to complete design projects for clients from industry and government. Two year-long pilot course sequences were successfully completed in the project; formative and summative evaluations from students, faculty, and clients all rated the program favorably. Results from our project have been widely disseminated at national engineering, communication, and education conferences and in engineering education journals.

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Executive Summary

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Overview and Purpose of the Project

This report summarizes our activities and accomplishments during a three year project to develop a curricular and pedagogical model for teaching multidisciplinary engineering design to senior-level undergraduate engineering students at the Colorado School of Mines (CSM). In this project, we are addressing concerns of industry and engineering education about the often narrow technical confines within which engineering design is currently taught. Our new two-semester design sequence employs multidisciplinary teams of students from chemical, mechanical, electrical, civil, geophysical, and metallurgical engineering and engineering physics working with engineering, science, and liberal arts faculty in cooperation with industrial clients to solve complex, open-ended, problems possessing numerous technical and non-technical constraints. The course is designed to help students: 1) creatively solve open-ended, "real world" design problems; 2) apply a multidisciplinary approach to these problems, simulating industrial experience; 3) work with other engineers, scientists, and non-technical professionals in small project design teams; 4) appreciate and consider non-technical constraints (ethical, political, aesthetic, environmental, economic, cultural, etc.) in their work; 5) develop client relations; 6) learn to conduct wide-ranging independent research; and 7) enhance their oral and written communication skills.

Background and Origins of the Project

The state of engineering education in this country has come under intense scrutiny in recent years, particularly as it influences our ability to compete in international high-technology markets. Several well-respected groups, including the National Science Board's Task Committee on Undergraduate Science, Mathematics, and Engineering Education; the American Society for Engineering Education Task Force; and the National Congress on Engineering Education have called for changes in the ways we educate engineers for the future. One major area of concern is engineering design which, according to a recent survey of industrial managers, should emphasize: 1) a multidisciplinary, team-based approach to solving problems, and 2) should allow students to recognize the value of collaboration rather than competition to achieve the desired result (a high-quality, well designed product or process). Our project attempted to address these concerns by providing a select group of senior-level engineering students an opportunity to work in design teams on "real-world" projects in a multidisciplinary, collaborative work environment.

Project Description

The design course is taught as a two-semester sequence; all participating students are required to complete both semesters' work and receive a total of 6 semester credit hours for their efforts. During a typical week, students attend one common lecture or discussion session dealing with engineering design topics of general interest. The remainder of their time is spent working on their cliented project with other members of their student design team under the direction of a faculty manager. Teams are composed of students from two or more of the seven participating disciplines; the composition of each team is determined by the technical requirements of each design project. Students are expected to meet weekly with their faculty managers to assess progress, discuss potential problems, and plan future activities. In addition, each team member is expected to work on the project individually and in the group for an additional 8-10 hours per week. Students are required to maintain a bound design notebook which documents their formal and informal design activities including a log which details the amount of time spent on each activity.

Project Results

The first pilot course. The first pilot multidisciplinary senior design course was taught starting in fall semester 1990. Twenty-three students (7 from chemical engineering, 5 from mechanical engineering, 3 from electrical engineering, 1 from civil engineering, 5 from metallurgical engineering, and 2 from engineering physics) participated in the course. Student design teams worked on four cliented projects: 1) building a new solar-powered car for the National Renewable Energy Laboratory, 2) building a bench-scale process development unit to produce samples of optically precise ceramic powders for Alpha Optical Systems, Inc. (a subsidiary of Coors Ceramics Company), 3) automating the control system on a diesel test engine for the Colorado Institute for High Altitude Fuels and Engine Research, and 4) building a computer-controlled bench-scale microcrystallizer apparatus for the National Institute for Standards and Technology. Each student design team successfully completed its prototype to the satisfaction of its client by the end of the pilot course and produced a professional quality design report.

The second pilot course. The second pilot multidisciplinary senior design course was taught starting in fall semester 1991. Twenty-four students (6 from chemical engineering, 6 from mechanical engineering, 4 from electrical engineering, 3 from civil engineering, 3 from metallurgical engineering, 1 from geophysical engineering, and 1 from engineering physics) participated in the course. Student design teams worked on five cliented projects: 1) building a feed mechanism for a corrugated board press for Union Camp, Inc., 2) designing a butane splitter tray column using vapor recompression for Koch Engineering Company, 3) monitoring subsurface contamination at a waste site using geophysical and sampling techniques for Roy F. Weston, Inc., 4) designing and building a corrosion demonstration package for the EG&G Rocky Flats plant, and 5) continuing to design and test a solar-powered car for the National Renewable Energy Laboratory. Once again, each student design team successfully completed its prototype or field work to the satisfaction of its client by the end of the pilot course and produced a professional quality design report.

The Future. Based on our successful implementation of the multidisciplinary design model developed in this project, the design course sequence will continue to be taught with institutional support from the Colorado School of Mines. Industrial funding on a project by project basis will be sought to support incidental expenses incurred by student design teams.

Project Evaluation

Evaluation played an important role in determining our ability to achieve the course objectives listed earlier. We used multiple instruments, quantitative and qualitative, formative and summative, short-term and long-term, to guide our program and ultimately determine its success. Results of our studies are summarized below.

Student Perceptions of the Design Process. We conducted an extensive evaluation process to study the perceptions of students in the pilot design course on various aspects of the engineering design process by evaluating students in both pilot courses near the end of each semester of the two-semester design sequence. We also evaluated senior design students who were enrolled in each department's discipline-specific design course. These evaluations were conducted near the end of each course. Our students overwhelmingly agreed that multi-disciplinary design teams tend to produce better engineering designs because of the broader range of expertise available to the team. As a whole, students in the discipline-specific design courses tended not to appreciate the importance of a multidisciplinary approach to design.

Our students strongly agreed that higher order thinking skills such as open-ended problem solving abilities, engineering analysis, and engineering synthesis were important to the design process. As a general trend, our students were slightly more aware of the importance of these skills than students in the discipline-specific design courses, although all students acknowledged the need to apply these skills to design work. Our students also understood the differences between engineering methods and the scientific method and have a good idea of the goals of the design process. Students from the discipline-specific design courses tended not to understand these concepts as well.

Student Evaluations of the Pilot Courses. Students responses to the course were quite positive and they seemed to be satisfied with the course structure and curriculum. Thus, we conclude that students can thrive in a multidisciplinary environment if the course is designed correctly, even though they have very little experience in these kinds of activities in their other coursework. As part of the students' self evaluation, they were asked to tell us their impressions of working in a multidisciplinary team and what they had learned by doing so. Generally, the students were quite positive about their experiences and seemed to appreciate the need for the types of activities they were asked to conduct.

Project Dissemination

We viewed effective dissemination of our results and experiences from this project not only as a professional obligation but also as an opportunity to help improve the teaching of design at engineering schools across the United States. Even though our pilot course has been taught only twice, we have already made or had accepted 10 presentations at engineering and education conferences and written 11 papers describing the multidisciplinary engineering design concept and the status of our pilot program. Several of these presentations and papers also describe other innovative educational programs at CSM and show how the FIPSE-sponsored work complements these efforts. The response to our dissemination activities has been over-whelmingly positive and numerous colleagues at other institutions have requested additional detailed curricular and pedagogical information.

Table of Contents

Section	Page
Overview and Purpose of the Project	1
Background and Origins of the Project	1
Project Description	5
Project Results	9
Project Continuation Plan	14
Project Evaluation	14
Project Dissemination	17
References Cited	20
Appendices	
A - Industrial Design Questionnaire and Summary of Survey Results	A-1
B - Course Syllabi for First MSD Pilot Course (1990-91) and Second MSD Pilot Course (1991-92)	B-1
C - Client Letters for MSD Projects and Executive Summaries and Tables of Content from Student Design Reports	C-1
D - Student Recruiting Flyer for MSD Program	D-1
E - Student Perception Questionnaire and Summary of Survey Results	E-1
F - Course, Peer, and Self Evaluation Questionnaires and Summary of Survey Results	F-1
G - Client Evaluation Form and Summary of Survey Results	G-1
H - Articles Publicizing the MSD Program Published in Mines Magazine	H-1

Overview and Purpose of the Project

This report summarizes our activities and accomplishments during a three year project to develop a curricular and pedagogical model for teaching multidisciplinary engineering design to senior-level undergraduate engineering students at the Colorado School of Mines (CSM). In this project, we are addressing concerns of industry and engineering education about the often narrow technical confines within which engineering design is currently taught. Our new two-semester design sequence employs multidisciplinary teams of students from chemical, mechanical, electrical, civil, geophysical, and metallurgical engineering and engineering physics working with engineering, science, and liberal arts faculty in cooperation with industrial clients to solve complex, open-ended, problems possessing numerous technical and non-technical constraints. The course is designed to help students meet the following objectives:

- creatively solve open-ended, "real world" design problems
- apply a multidisciplinary approach to these problems, simulating industrial experience
- work with other engineers, scientists, and non-technical professionals in small project design teams
- appreciate and consider non-technical constraints (ethical, political, aesthetic, environmental, economic, cultural, etc.) in their work
- develop client relations
- learn to conduct wide-ranging independent research
- enhance their oral and written communication skills

The remainder of this report describes in more detail our accomplishments in developing and teaching the multidisciplinary design course. We will also discuss results of our project evaluation and dissemination activities and plans for continuation of the multidisciplinary senior design program beyond FIPSE support.

Background and Origins of the Project

The state of engineering education in this country has come under intense scrutiny in recent years, particularly as it influences our ability to compete in international high-technology markets. Several well-respected groups, including the National Science Board's Task Committee on Undergraduate Science, Mathematics, and Engineering Education; the American

Society for Engineering Education Task Force; and the National Congress on Engineering Education have called for changes in the ways we educate engineers for the future. One major area of concern is engineering design which, according to the most recent ABET (Accreditation Board for Engineering and Technology) guidelines, should include at least some of the following features:

> "development of student creativity, use of open-ended problems, development and use of design methodology, formulation of design problem statements and specifications, consideration of alternative solutions, feasibility considerations, and detailed system descriptions. Further, it is desirable to include a variety of realistic constraints such as economic factors, safety, reliability, aesthetics, ethics, and social impact."

The recent Association of American Colleges report "Unfinished Design -- The Humanities and Social Sciences in Undergraduate Engineering Education" has also emphasized the need to better integrate liberal arts studies into engineering education and, in particular, to provide students with a design experience that encompasses technical, humanistic, and socially relevant aspects. According to a recent survey of industrial managers published in ASEE *Prism*, design education should: 1) emphasize a multidisciplinary, team-based approach to solving problems, and 2) allow students to recognize the value of collaboration rather than competition to achieve the desired result (a high-quality, well designed product or process).

Instead of addressing these concerns, most design courses at U.S. colleges and universities treat design as solving well-defined problems which differ from engineering science exercises only by having multiple possible solutions. The widespread acceptance of this design model is illustrated by the number of engineering design texts available in various disciplines complete with "answer" books for faculty use. In such a curriculum, technical and non-technical concerns are clearly separated, as Figure 1 illustrates. If students make connections, they do so only by chance. For the most part their technical courses remain focused on "number crunching" instead of the "big picture." At the Colorado School of Mines (CSM) we have moved away from narrow training of engineering students and instead attempt to broadly educate them by giving them opportunities to practice the kinds of integrative, creative thinking they will need to solve the increasingly complex problems they will face as practicing engineers. We begin this

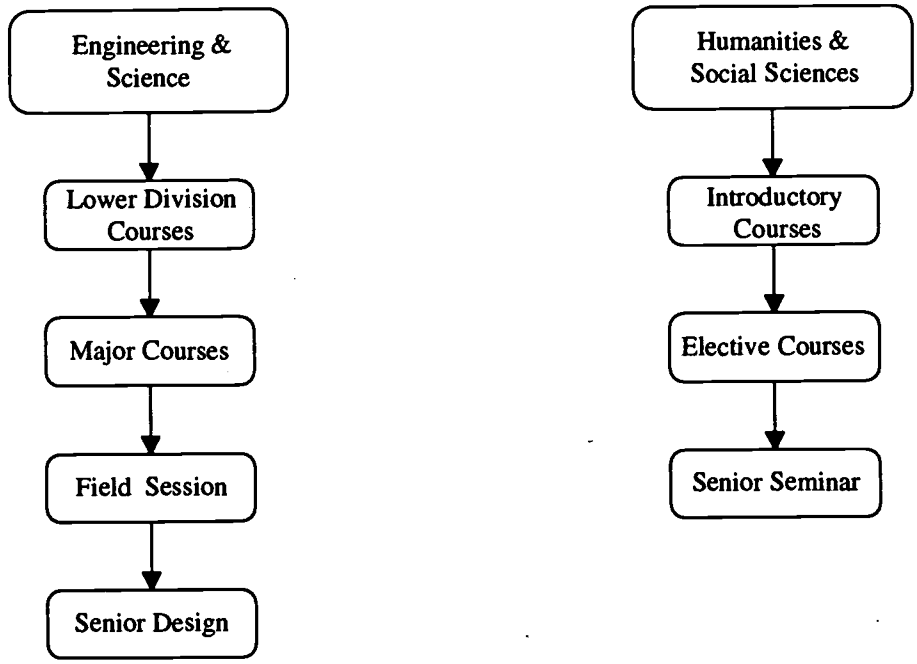

Figure 1 - Traditional Non-Integrated Undergraduate Engineering Curriculum

process at the lower division level with our nationally-recognized EPICS (Engineering Practices Introductory Course Sequence) requirement . EPICS is an eleven credit hour, four semester sequence required of all freshmen and sophomores at CSM. The sequence combines instruction and practice in open-ended problem solving, graphics, computing, technical oral and written communications, and group dynamics. The two major goals of EPICS are to enhance our students' abilities to: 1) solve complex, "real world" cliented problems with numerous technical and non-technical (social, environmental, ethical, etc.) constraints, and 2) professionally communicate the results of their work orally and in writing. In our experience, the EPICS program provides students with valuable problem-solving, teamwork, and communication skills prior to their senior-level engineering design experience.

Our success with EPICS provided the incentive to extend multidisciplinary design studies to the senior level. We wanted to give students the opportunity to continue improving their problem-solving, group work, and communications skills while at the same time learning to apply their newly-acquired technical knowledge to solving technically sophisticated problems for industrial and government clients. As shown in Figure 2, the Multidisciplinary Senior

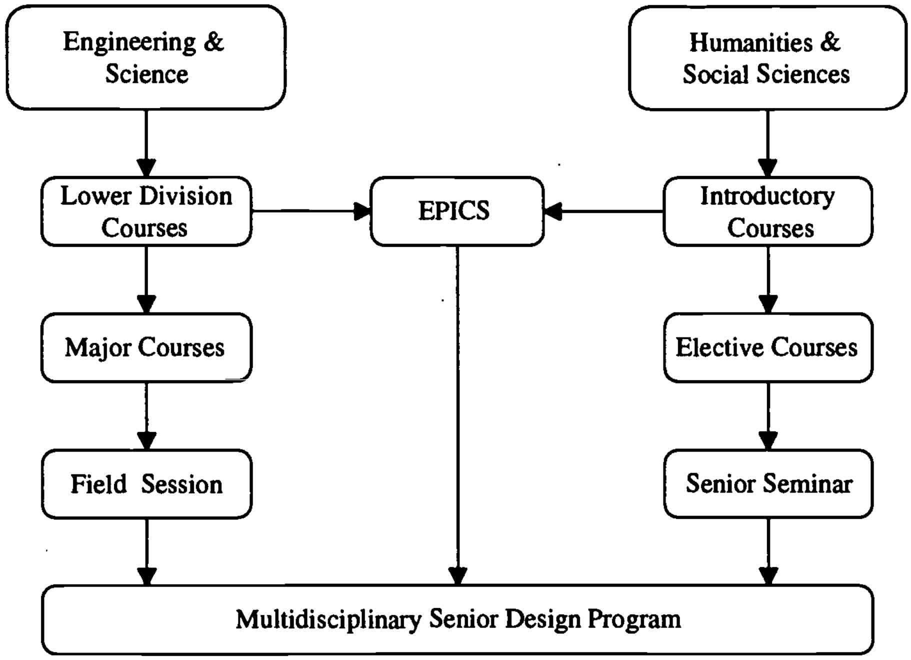

Figure 2 - Integration of EPICS and Multidisciplinary Senior Design into CSM Curriculum

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Design (MSD) program provides us with a curricular structure that includes some aspects of engineering design throughout our students' undergraduate studies and emphasizes the need to consider a multidisciplinary approach to solving "real-world" problems.

Institutional context. The Colorado School of Mines is the second oldest and one of the largest colleges of mineral engineering in the nation. CSM offers undergraduate and graduate degrees in chemical engineering, engineering (mechanical, electrical, and civil options), geological engineering, geophysical engineering, mining engineering, metallurgical engineering, chemistry, engineering physics, engineering mathematics, petroleum engineering, mineral economics, and environmental science. In addition, the well-respected non-degree granting division of liberal arts and international studies provides opportunities for engineering and applied science students to be exposed to the richness of humanities and social science disciplines. The School has distinguished itself as a leader in undergraduate engineering education for many years.

CSM's small size and outstanding student body make it an ideal place to pilot a study such as the one we conducted. The undergraduate student body of approximately 2000 is extremely talented, with the average freshman ranking approximately in the 90th percentile in mathematical skills and 80th percentile in verbal skills according to such nationally normed tests as ACT and SAT. Entrance requirements are among the highest in the nation for public institutions of higher education. Such a capable student body was ideally suited for piloting the multidisciplinary design program.

Project Description

This section of the report describes each of the project tasks we completed in order to plan, develop, and implement the multidisciplinary senior design course sequence.

Industrial design questionnaire. To ensure that our new course sequence adequately addressed industrial concerns and needs as realistically as possible, we developed a questionnaire early in the project to collect data on the organization, management, evaluation, and communications activities of representative industrial design teams. The questionnaire (shown in Appendix A) was sent to 177 companies and government agencies which actively recruit and hire our B.S. graduates for entry-level engineering positions; 67 completed questionnaires (38% of the total) were returned and we observed several interesting trends in the responses (a detailed distribution of the results is provided in Appendix A).

About 75% of the companies and agencies surveyed used design teams of 6 members or fewer and nearly 75% of these teams were multidisciplinary in nature. These results confirmed our original premise that students should be exposed to realistic design projects requiring input from several disciplines in order to better prepare them for entry-level industrial or government positions.

The survey also asked respondents to rank order six attributes (technical knowledge, communication skills, ability to work in small groups, ability to self-educate, ability to consider non-technical constraints, and ability to accommodate a multidisciplinary approach to problem-solving) they would like to see in CSM graduates. Clearly, each attribute was considered important by all respondents; several commented that all six were very important and none could be considered more or less valuable than the others. The lesson we learned is that industry values several skills and attributes in addition to technical knowledge, although few traditional engineering design courses address these needs. The message is clear: engineering design courses need to do a better job of imparting skills which have not often been associated with traditional science-based education even if it means some reduction in technical content. These findings formed the philosophical basis for the two-semester multidisciplinary design sequence developed in this project. As described in the next section of this report, our course allowed students to become more proficient in each of the six attributes listed above, primarily by giving them responsibilities and project work which required application of these skills to successfully achieve their project objectives and satisfy client expectations.

Course structure. Because of the organizational complexities associated with managing students and faculty from seven academic disciplines, a detailed management structure was developed as illustrated in Figure 3. Day-to-day project management was provided by Dr. Ronald L. Miller and Dr. Barbara M. Olds, the project directors, who periodically reported progress to Dr. Franklin Schowengerdt, the Vice-President for Academic Affairs. The pilot courses were team-taught by Drs. Miller and Olds and the Design Management Team (DMT) which was composed of faculty members from each participating engineering department. Each DMT faculty member also acted as manager for one or more multidisciplinary student design teams. Faculty members who served on the DMT during the project are listed in Table I.

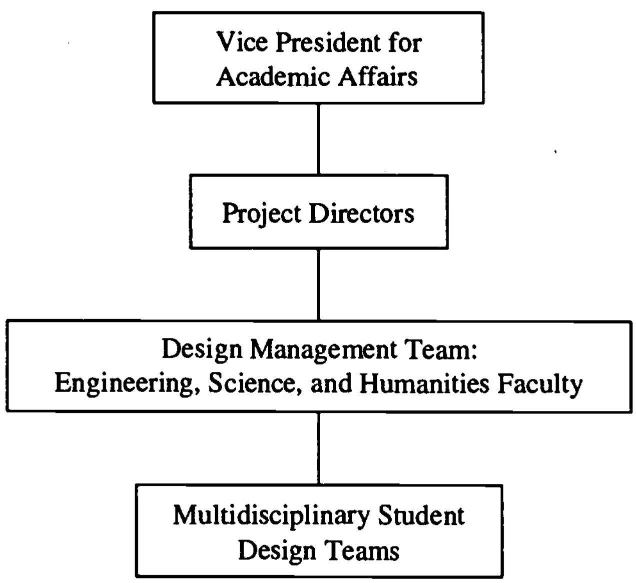

Figure 3 - Management Structure of the Multidisciplinary Senior Design Program

Table I

Members of the CSM Design Management Team

- Dr. Ronald Miller - Chemical Engineering and Petroleum Refining
- Dr. Barbara Olds - Liberal Arts and International Studies
- Dr. William Copeland - Metallurgical and Materials Engineering
- Dr. Robert Knecht - Chemical Engineering and Petroleum Refining
- Dr. Nigel Middleton - Engineering {Mechanical, Electrical, Civil options}
- Dr. Cathy Skokan - Geophysical Engineering
- Dr. John Trefny - Engineering Physics

The design course is taught as a two-semester sequence; all participating students are required to complete both semesters' work and receive a total of 6 semester credit hours for their efforts. During a typical week, students attend one common lecture or discussion session dealing with engineering design topics of general interest. The remainder of their time is spent working on their cliented project with other members of their student design team under the direction of a DMT faculty manager. Teams are composed of students from two or more of the seven participating disciplines; the composition of each team is determined by the technical requirements of each design project. Students are expected to meet weekly with their faculty managers to assess progress, discuss potential problems, and plan future activities. In addition, each team member is expected to work on the project individually and in the group for an additional 8-10 hours per week. Students are required to maintain a bound design notebook which documents their formal and informal design activities including a log which details the amount of time spent on each activity.

Tables II and III summarize course topics covered in the weekly common lecture/discussion sessions. As shown in Table II, during the fall semester project teams are organized, problem formulation begins, and self-education techniques are reviewed and implemented. Students are taught the importance of effective time management and professional

Table II

Summary of Fall Semester Design Course Topics

- Project team organization
- Problem formulation and self-education
- Time management
- Professional oral, written, and graphical communications
- Engineering design processes
- Engineering analysis strategies
- Proposal preparation

Table III

Summary of Spring Semester Design Course Topics

- Review of engineering design processes
- Engineering synthesis strategies
- Liability and safety issues
- Personal and professional ethics
- Sexual harassment and discrimination in the professional environment
- Patent disclosure issues in engineering design
- Final oral and written report preparation
- Public demonstrations of team designs

oral, written, and graphic communications in their work. Much of the fall semester is devoted to discussing the engineering design process with particular emphasis on analysis of alternative solution strategies. Each design team completes analysis and design tasks unique to its design project and reports its progress with numerous written and oral progress reports. Thus, each student in the course is exposed to selected topics common to the design process and, at the same time, becomes knowledgeable about technical topics unique to his or her own project. The major product from the fall semester course is a comprehensive written proposal outlining each design team's proposed project solution. The proposal document summarizes results from the design team's preliminary engineering analysis and design work. A work statement, proposed budget, and project completion schedule complete with intermediate milestones are also included in the proposal. The proposal is presented to the appropriate client in both written and oral form, and the client is asked to evaluate the quality of student work and provide suggestions for improvement.

During the spring semester, student groups spend most of their time implementing their proposed solutions by completing their engineering analysis, performing necessary synthesis tasks, optimizing their designs, and actually building and evaluating their prototypes or completing their field work. Each project culminates in a public demonstration of the prototype in operation or a detailed description of field work results. As shown in Table III, the weekly lecture/discussion sessions are devoted to engineering design topics such as liability and safety issues, ethics and whistleblowing, sexual harassment and affirmative action in the professional environment, and patent disclosure. Several of these class sessions include presentations by outside experts. For example, a patent attorney visits class during discussion of patent disclosure and patent law. Several oral and written progress reports as well as a final written report are also prepared in the spring semester course.

Project Results

The first pilot course. The first pilot multidisciplinary senior design course was taught starting in fall semester 1990. A detailed course syllabus for each semester of the course is included in Appendix B. Twenty-three students (7 from chemical engineering, 5 from mechanical engineering, 3 from electrical engineering, 1 from civil engineering, 5 from metallurgical engineering, and 2 from engineering physics) participated in the course. Student design teams worked on four cliented projects: 1) building a new solar-powered car for the National Renewable Energy Laboratory, 2) building a bench-scale process development unit to produce samples of optically precise ceramic powders for Alpha Optical Systems, Inc. (a subsidiary of Coors Ceramics Company), 3) automating the control system on a diesel test engine for the Colorado Institute for High Altitude Fuels and Engine Research, and 4) building a computer-controlled bench-scale microcrystallizer apparatus for the National Institute for Standards and Technology. Each project is described briefly in Table IV; client letters outlining each project's problem statement are presented in Appendix C.

Table IV

Descriptions of Projects Used in 1990-91 Pilot Design Course

<u>Solar Electric Vehicle</u> - Design, build, and test a prototype solar electric vehicle for competitions such as the GM Sunrayce. Prepare comprehensive design packages for photovoltaic modules, energy storage, chassis, motor and drivetrain, and aerodynamic body.

<u>Optical Spinel Manufacture</u> - Design, build, and operate a bench-scale apparatus to produce optically pure samples of transparent polycrystalline $MgAl_2O_4$ using the sol-gel alkoxide process developed at CSM. Prepare quantities of spinel samples sufficient for chemical and optical analysis.

<u>Control System for Stationary Diesel Engine</u> - Design and install control instrumentation, a new cooling system, and gas and liquid fuel supply systems for a CFR-type compression octane testing engine. Evaluate control system performance and fine-tune dynamic response to client specifications using standard gaseous and liquid fuels.

<u>Automated Microcrystallizer</u> - Design, build, and operate a computer-controlled bench-scale microcrystallizer apparatus to grow near perfect protein crystals using osmotic dewatering as the water removal technique. Evaluate system performance (nucleation and growth rates) using standard aqueous protein solutions.

Each student design team successfully completed its prototype to the satisfaction of its client by the end of the pilot course and produced a professional quality design report. Copies of each team's executive summary and table of contents are included in Appendix C. A public presentation of each team's project solution and prototype demonstration was held on April 24, 1991 where each student group presented an excellent summary of its work. Each client sent a representative to the presentations; approximately 40 faculty and students from the CSM campus also attended as did several staff members of the CSM Public Relations office who provided additional publicity about the program in several CSM publications. Several students commented after completing their presentations that they were glad to have the opportunity to describe their accomplishments to friends and colleagues from the campus community. This experience also reinforced to the students the importance of professional conduct and professional communications in engineering design practice.

The second pilot course. The second pilot multidisciplinary senior design course was taught starting in fall semester 1991. A detailed course syllabus for each semester of the course is included in Appendix B. Twenty-four students (6 from chemical engineering, 6 from mechanical engineering, 4 from electrical engineering, 3 from civil engineering, 3 from metallurgical engineering, 1 from geophysical engineering, and 1 from engineering physics) participated in the course. Student design teams worked on five cliented projects: 1) building a feed mechanism for a corrugated board press for Union Camp, Inc., 2) designing a butane splitter tray column using vapor recompression for Koch Engineering Company, 3) monitoring subsurface contamination at a waste site using geophysical and sampling techniques for Roy F. Weston, Inc., 4) designing and building a corrosion demonstration package for the EG&G Rocky Flats plant, and 5) continuing to design and test a solar-powered car for the National Renewable Energy Laboratory. Each project is described briefly in Table V; client letters outlining each project's problem statement are presented in Appendix C.

Once again, each student design team successfully completed its prototype or field work to the satisfaction of its client by the end of the pilot course and produced a professional quality design report. Copies of each team's executive summary and table of contents are included in Appendix C. A public presentation of each team's project solution was held on April 29, 1992 and each student group presented an excellent summary of its work. Once again faculty and

Table V

Descriptions of Projects Used in 1991-92 Pilot Design Course

Feed Mechanism for Corrugated Board Press - Prepare detailed engineering specifications for an automated feed mechanism to lift corrugated boards from a stack to the feed hopper of a board press. Simulate feeder control system and fine-tune dynamic response to client specifications.

Butane Splitter - Evaluate process alternatives for separating a mixed stream of isobutane and normal butane using traditional and vapor recompression distillation configurations. Optimize the design of each column configuration and estimate project costs for a 10 year project life.

Waste Site Remediation - Monitor subsurface contamination at a specific site from leaking diesel oil and gasoline storage tanks using geophysical techniques, soil sampling, and water sampling. Confirm that the site is suitable for use as a city park or recommend additional remediation actions.

Corrosion Demonstration - Design, build, and operate a series of small scale corrosion demonstration packages to introduce principles of corrosion and corrosion protection to engineers and technicians. Prepare and deliver a one-hour corrosion short course using the packages developed.

Solar Electric Vehicle - Design, build, and test a prototype solar electric vehicle for competitions such as the GM Sunrayce. Prepare comprehensive design packages for photovoltaic modules, energy storage, chassis, motor and drivetrain, and aerodynamic body.

students from the CSM campus attended the presentations and were impressed with the quality of student work displayed. Again, several of the design students commented after completing their presentations that they were glad to have the opportunity to describe their project work to interested people in the campus community.

Evaluation activities. Evaluation activities were initiated during the second year of this project as the first pilot design course was taught; these activities were continued during the project's third year as we taught the second pilot design course. Most of our efforts were directed towards measuring selected outcomes from the students participating in the multidisciplinary senior design pilot course. Many of these outcomes were compared with similar outcomes demonstrated by senior engineering students completing traditional discipline-specific design courses at CSM. We also measured student satisfaction with all aspects of the course sequence including the pedagogy used and client satisfaction with the final designs received from the student design teams. Details of our evaluation activities and results are described beginning on page 14.

Dissemination activities. Throughout the project, we have actively disseminated the encouraging results of the multidisciplinary senior design program by discussing our work at several regional and national educational conferences and by publishing papers in selected educational and engineering journals. Details of these dissemination activities are described beginning on page 17.

Industrial clients and projects. Each member of the DMT continues to be involved in cultivating prospective clients for future design courses. We continue to see a very positive response to our program by clients from both government and industry; for example, we already have more prospective projects available for use in next year's course than we will be able to accommodate. Most of the clients from the first and second pilot courses have indicated their willingness to continue working with us and several new companies have asked to provide projects. Many of the students who have already committed to the 1992-93 course have done so because they specifically want to work on one of the these projects.

Student recruiting. During the late spring and summer of 1992, students from chemical engineering, metallurgical engineering, engineering physics, engineering (mechanical, electrical, civil options), geophysical engineering, and mathematics were recruited and encouraged to participate in our 1992-93 course. Because of our success in the first two pilot design courses, we have found that little formal recruiting is now needed to obtain motivated students for our program. Rather, "word of mouth" recruiting from students who have completed the first and second pilot courses has attracted their friends and classmates to the program. For example, of the students who participated in the second pilot course, nearly 75% know someone who participated in the first pilot course. We also attract students who observed one of the public presentations of design team solutions. To ensure that every qualified CSM student has access to the program, we mailed a recruiting flyer (shown in Appendix D) to students who have pre-registered for their traditional senior design course describing the program and inviting them to our organizational meeting held during the first week of classes in the fall semester. Our long term goal is to attract approximately 30-40 highly motivated and talented students to the program per year; such an enrollment level will ensure the proper degree of faculty/student interaction to make our course a continued success.

Project Continuation Plan

During the last three years, we have developed detailed plans to continue the MSD program beyond its FIPSE-sponsored pilot phase. For example, we continue to successfully recruit more CSM academic departments into the program as evidenced by the expansion of our second pilot design course to include an "earth sciences" component involving geophysical engineering. We have expanded this component further for the 1992-93 design course by attracting other CSM departments including mathematics.

The program will continue to be financially supported by both CSM and extramural resources. Salary costs will become part of the CSM institutional budget while individual project expenses will become the responsibility of clients who provide MSD projects. Proposals to request additional extramural funding have been submitted to the CSM Center for Geoscience Computing and to the Colorado Commission on Higher Education Programs of Excellence competition.

Project Evaluation

Evaluation played an important role in determining our ability to achieve the course objectives listed in the introduction to this report. We used multiple instruments, quantitative and qualitative, formative and summative, short-term and long-term, to guide our program and ultimately determine its success. Since our ultimate goal was to prepare students who are creative, well-rounded problem solvers, we collected data from faculty, client representatives, and students in a variety of ways and compared (statistically whenever possible) both progress and performance of the students in our pilot courses with those in the traditional senior engineering design courses at CSM. These results are presented in the following subsections.

Student Perceptions of the Design Process. We conducted an extensive evaluation process to study the perceptions of students in the MSD pilot design course on various aspects of the engineering design process. Using questionnaires shown in Appendix E, we evaluated students in both pilot courses near the end of each semester of the two-semester design sequence. We also evaluated senior design students from chemical engineering, metallurgical engineering , engineering [mechanical, electrical, and civil options], and engineering physics who were enrolled in each department's discipline-specific design course. These evaluations were conducted near the end of each course. As shown in Figure E-1 (Appendix E), students in the multidisciplinary pilot design courses (hereafter referred to as "MSD students") overwhelmingly agreed that multidisciplinary design teams tend to produce better engineering designs because of the broader range of expertise available to the team. As a whole, students in the discipline-specific design courses tended not to appreciate the importance of a multidisciplinary approach to design. These data suggest that our original goal of introducing students to an industrially realistic design experience using multidisciplinary teams of students has been achieved and that the MSD students understand and appreciate the importance of a multidisciplinary approach to solving most open-ended, "real-world" problems.

MSD students strongly agreed that higher order thinking skills such as open-ended problem solving abilities, engineering analysis, and engineering synthesis were important to the design process as shown in Figures E-2, E-3, and E-4. As a general trend, MSD students were slightly more aware of the importance of these skills than students in the discipline-specific design courses, although all students acknowledged the need to apply these skills to design work. Figures E-5 and E-6 summarize the results from two questions in which students were asked to characterize the nature and scope of the design process and to contrast engineering design with applications of the scientific method. While not a rigorous evaluation of critical thinking skills, these questions were designed to evaluate the extent to which students had assimilated class discussions about engineering design and had begun to synthesize the design process in their own minds. Data shown in Figures E-5 and E-6 suggest that MSD students understood the differences between engineering methods and the scientific method and have a good idea of the goals of the design process. Students from the discipline-specific design courses tended not to understand these concepts as well.

Figures E-7, E-8, and E-9 summarize results from a series of questions designed to evaluate whether or not students understood the importance of several "non-technical" aspects of the design process. As shown in these figures, MSD students strongly agreed that communication skills, ethical considerations, and safety issues were important considerations in engineering design; students from the discipline-specific design courses also agreed that these were important considerations but did not agree quite as strongly as MSD students. Overall, these results were quite encouraging, since they suggest that the students' exposure to "non-technical" design issues in their freshman and sophomore EPICS courses still influenced their design philosophy in a positive manner.

Student Evaluations of the Pilot Courses. MSD students evaluated the course, their peers, and themselves using the evaluation forms shown in Appendix F. These data were used to improve the pilot course sequence and will continue to be used in planning and improving future MSD design courses. The peer and self evaluation data were also used as part of the course grading process so that not all team members received the same final grade even though most oral and written reports were prepared and delivered as team efforts.

Figures F-1 through F-6 summarize the students' satisfaction with course content and organization, technical work, written and oral communication work, and selected design topics discussed in class. These data are important to collect and evaluate because none of the students was familiar with working in a multidisciplinary classroom environment and we had to ensure that they could function successfully in such an environment. As shown, students' responses to the course were quite positive and they seemed to be satisfied with the course structure and curriculum. Thus, we conclude that students can thrive in a multidisciplinary environment if the course is designed correctly, even though they have very little experience in these kinds of activities in their other coursework. As part of the students' self evaluation, they were asked to tell us their impressions of working in a multidisciplinary team and what they had learned by doing so. Student comments collected on the self evaluation forms are summarized in Appendix F. Generally, the students were quite positive about their experiences and seemed to appreciate the need for the types of activities they were asked to conduct.

Client Evaluations. Using the evaluation form shown in Appendix G, we asked each project client to evaluate the performance of his/her student design team in the categories of technical quality, problem-solving ability, communications quality, and overall team performance. As shown in Appendix G, clients rated the student teams highly in all four categories; 67% of the clients rated their team's overall performance as above average or excellent. Problem-solving abilities and the technical quality of the final design were judged above average or excellent by 83% of the clients. Over 60% of the clients also rated the quality of the final oral and written reports as above average or excellent.

We also received substantial anecdotal evidence that each client was quite pleased with the final products developed by the design teams (design specifications, prototype development and construction, final oral and written reports, etc.). For example, Dr. Michael Graboski, the client representative for the stationary diesel engine project, told us that the refurbished engine and control system was fully operational and performing better than the original specifications given to the student design team. He noted that a new engine and control system equivalent to the system built by the students would cost more than $150,000, while the students have spent less than $20,000 rebuilding and improving the existing engine system.

Project Dissemination

We view effective dissemination of our results and experiences from this project not only as a professional obligation but also as an opportunity to help improve the teaching of design at engineering schools across the United States. Even though our pilot course has been taught only twice, we have already made or had accepted 10 presentations at engineering and education conferences and written 11 papers describing the multidisciplinary engineering design concept and the status of our pilot program. Several of these presentations and papers also describe other innovative educational programs at CSM and show how the FIPSE-sponsored work complements these efforts. The response to our dissemination activities has been overwhelmingly positive and numerous colleagues at other institutions have requested additional detailed curricular and pedagogical information. Presentations and publications describing our work are listed below in inverse chronological order:

Presentations:

1) "Writing and Design Throughout the Engineering Curriculum: A Model," Conference on Writing in Engineering Design, Houghton, Michigan, June 24-26, 1992.

2) "Technical Writing: An Essential Component of the Engineering Design Process," American Society for Engineering Education Annual Meeting, Toledo, Ohio, June 21-25, 1992.

3) "Clients, Projects, and Technical Communications For Engineers: (Dis)Courses Across the Curriculum," Conference on College Composition and Communication, Cincinnati, Ohio, March 19-21, 1992.

4) "Teaching Design in a Multidisciplinary Environment at the Colorado School of Mines," American Institute of Chemical Engineers Annual Meeting, Los Angeles, California, November 17-22, 1991.

5) "Introducing Students to Design, Communication, and Teamwork Skills," Accreditation Board for Engineering and Technology Annual Meeting, Chicago, Illinois, October 24-25, 1991.

6) "Are Departments Obsolete?" Frontiers in Education Conference, West Lafayette, Indiana, September 22-24, 1991.

7) "Liberal Studies in the CSM Design Curriculum," American Society for Engineering Education Conference, New Orleans, Louisiana, June 16-19, 1991.

8) "Design Across the Engineering Curriculum at the Colorado School of Mines," American Society for Engineering Education Rocky Mountain Regional Meeting, Provo, Utah, April 18-19, 1991.

9) "Innovative Engineering Education at the Colorado School of Mines," Frontiers in Education Conference, Vienna, Austria, July 2-5, 1990.

10) "Using Industrial Clients in the Colorado School of Mines Design Sequence," American Institute of Chemical Engineers Annual Meeting, San Francisco, Nov. 5-10, 1989.

<u>Publications</u>:

1) "Writing and Design Throughout the Engineering Curriculum: A Model," B.M. Olds and R.L. Miller, Proceedings of the Conference on Writing in Engineering Design, pp. 151-156, Houghton, Michigan, June 24-26, 1992.

2) "Technical Writing: An Essential Component of the Engineering Design Process," B.M. Olds, Proceedings of the American Society for Engineering Education Annual Conference, pp. 1182-1186, Toledo, Ohio, June 21-25, 1992.

3) "Departments are Obsolete," B.M. Olds and R.L. Miller, ASEE Prism, p. 56, December 1991.

4) "Teaching Design in a Multidisciplinary Environment at the Colorado School of Mines," R.L. Miller and B.M. Olds, AIChE Annual Meeting, Los Angeles, California, November 17-22, 1991.

5) "Introducing Students to Design, Communication, and Teamwork Skills," B.M. Olds, Proceedings of the Accreditation Board for Engineering and Technology Annual Meeting, Chicago, Illinois, October 24-25, 1991.

6) "Are Departments Obsolete?" Proceedings of the Frontiers in Education Conference, pp. 213-216, West Lafayette, Indiana, September 22-24, 1991.

7) "Liberal Studies in the CSM Design Curriculum," R.L. Miller and B.M. Olds, Proceedings of the American Society for Engineering Education Annual Conference, pp. 170-173, New Orleans, Louisiana, June 16-19, 1991.

8) "Design Across the Engineering Curriculum at the Colorado School of Mines," Proceedings of the American Society for Engineering Education Rocky Mountain Regional Meeting, pp. 16-19, Provo, Utah, April 18-19, 1991.

9) "The 'Real World' in the Classroom: The Role of Industrial Clients in the Colorado School of Mines Design Sequence," International Journal of Applied Engineering Education, 6, 515, 1990.

10) "Innovative Engineering Education at the Colorado School of Mines," B.M. Olds, R.L. Miller, and D.W. Gentry, Proceedings of the Frontiers in Education Conference, pp. 260-262, Vienna, Austria, July 2-5, 1990.

11) "Using Industrial Clients in the Colorado School of Mines Design Sequence," B.M. Olds and R.L. Miller, American Institute of Chemical Engineers Annual Meeting, San Francisco, California, Nov. 5-10, 1989.

In addition to formal dissemination activities involving presentations at conferences and publications in educational, engineering, and communications journals, we will continue "networking" with administrators and faculty at other engineering schools to educate them about our project and encourage them to adapt our model to their institutional context. We will also continue to publicize our multidisciplinary design program in CSM publications which are widely distributed in the United States and the world. For example, Appendix H contains two articles describing the program which were published in Mines Magazine, a publication of the CSM Alumni Association with world-wide circulation of approximately 25,000.

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Appendix A

Industrial Design Questionnaire
and
Summary of Survey Results

Colorado School of Mines
Multidisciplinary Senior Design Program

Engineering Design Questionnaire

Company: ______________________________ Date: ____________

Division: ____

Contact Person: ____

Address: ________________________ Phone: _________________

____

When the term design team or design group is used in this questionnaire, it should be considered synonymous with product development team, project development team or similar terms so long as the team's efforts are focused on the evolution of a system, component, or process intended to meet desired needs.

1. In your company, how many people are involved in a typical design group?
   _____ 1 - 3 _____ 4-6 _____ more than 6

2. Are these design groups generally
   _____ multidisciplinary (people involved have several different educational backgrounds) _____ from a single discipline

3. Who generally supervises the design groups? ______________________________

4. Who selects the design groups?
   _____ project supervisor _____ the team members
   _____ other (please specify) ____________________________

5. How are the design groups selected?
   _____ by project need _____ by the skills of individual members
   _____ other (please specify) ____________________________

6. How long does a typical project last?
   _____ 1 week to 1 month _____ 1 month to 3 months _____ 3 months to 6 months
   _____ over 6 months

7. How often does the design team meet?
   _____ almost daily _____ weekly _____ twice a month
   _____ monthly

8. Do you make use of any structured problem-solving techniques?

_____ yes _____ no

If yes, please describe briefly.

9. What are the end products of your design team's work? Please check as many as apply.

_____ a written report _____ an oral report _____ a model or prototype

_____ other (please specify) ________________________________

10. Do you make oral or written progress reports during the project's duration?

_____ written _____ oral

11. Approximately how often do you report?________________________

12. Who is responsible for producing your oral and written reports?

_____ a designated member of the team _____ the entire team

_____ all members of the team on a rotating basis _____ a staff technical writer

13. How is team performance evaluated?

_____ by team members _____ by a team leader _____ by the project supervisor

14. Briefly describe the type and frequency of evaluations.

15. What qualities are you looking for in the new CSM graduates that your company hires? Please rank the following attributes from 1 (least important) to 6 (most important):

_____ technical knowledge and skills

_____ communication skills (oral and written)

_____ ability to work well in small groups

_____ ability to self-educate and self-start

_____ ability to analyze and consider non-technical constraints in solving a problem

_____ ability to consider a multidisciplinary approach to solving problems.

16. How would you rate the following qualities for CSM graduates you have recently hired? Please use the following scale:

5 - excellent
4 - above average
3 - average
2 - below average
1 - poor

_____ technical knowledge and skills
_____ communication skills (written and oral)
_____ ability to work well in small groups
_____ ability to self-educate and self-start
_____ ability to analyze and consider non-technical constraints in solving a problem.
_____ ability to consider a multidisciplinary approach to problem solving.

17. What areas would you like us to stress in our new senior design program?

18. Do you have design projects you might be interested in working with us to develop in the new design sequence? If so, please describe briefly.

19. Would you be willing to allow us to make a site visit to observe and discuss your company's design project procedures?

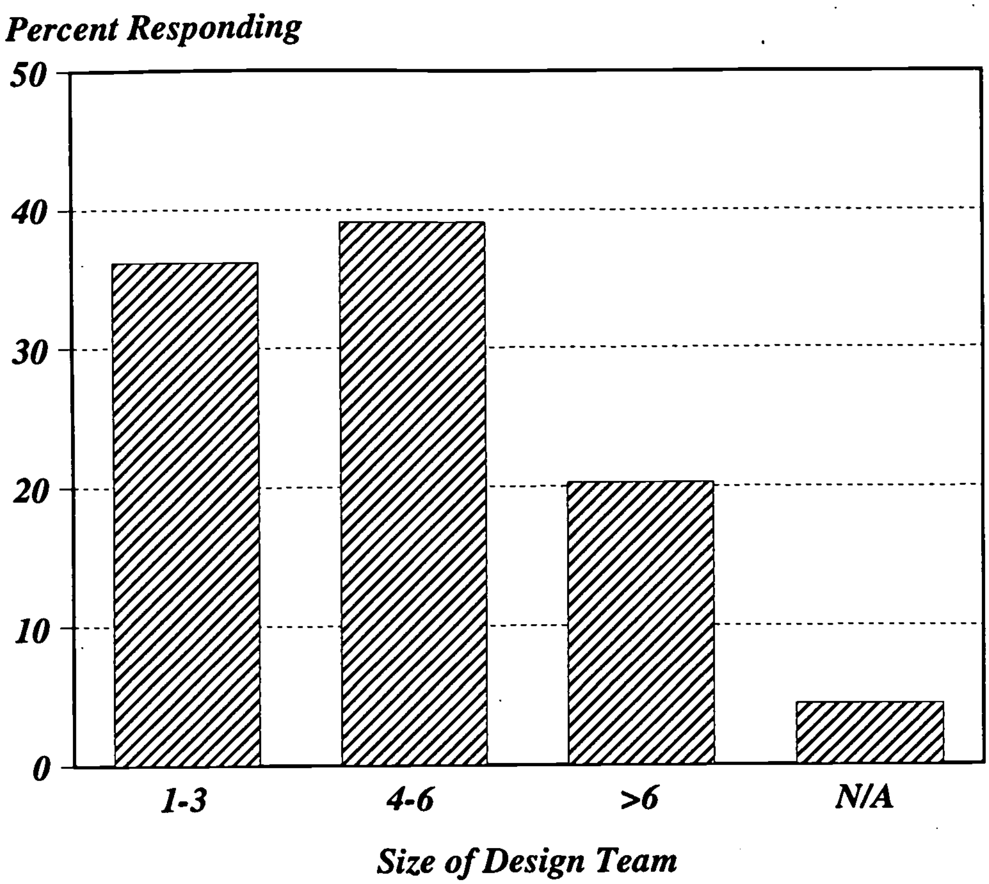
20. Would you like to see a summary of results from this questionnaire? To whom should we send it?

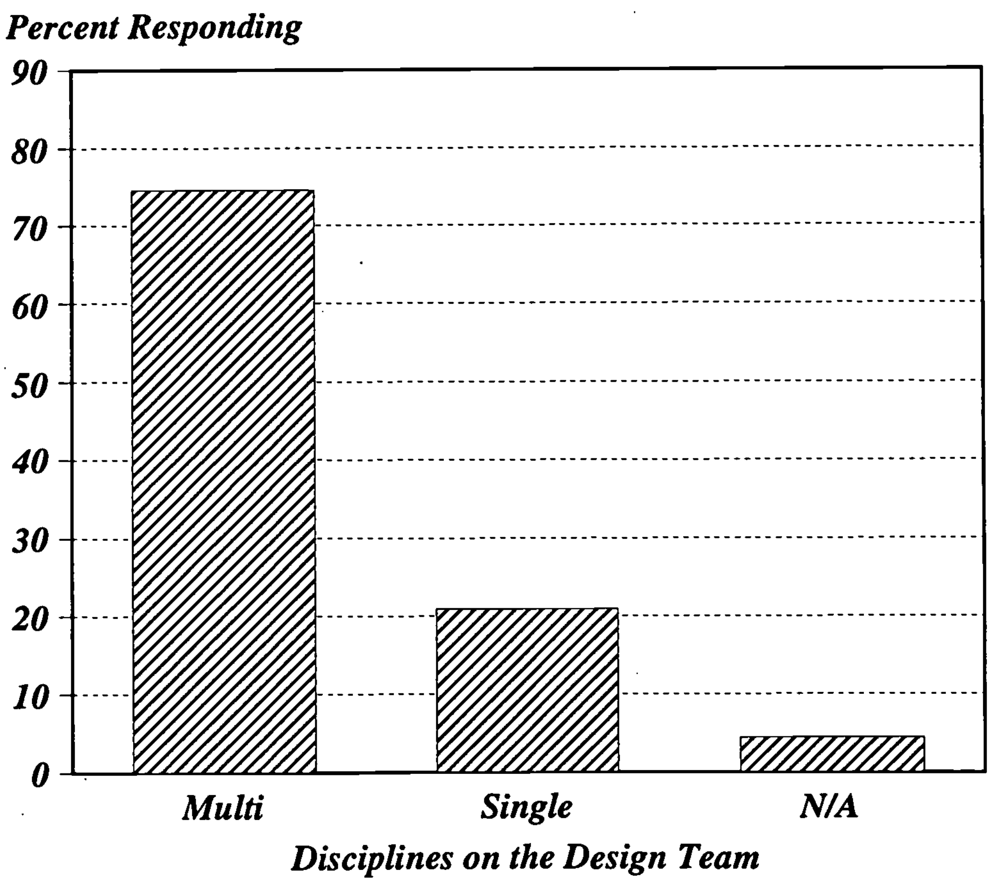
Name: ____

Address: ____

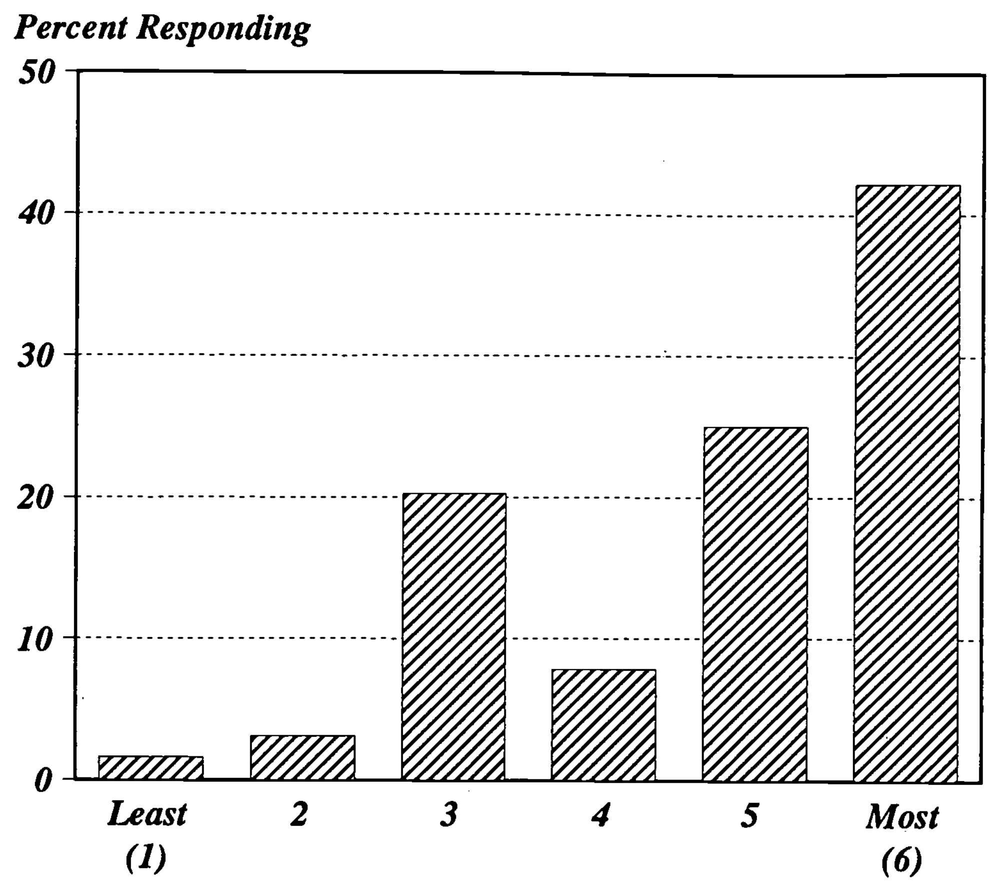
____

____

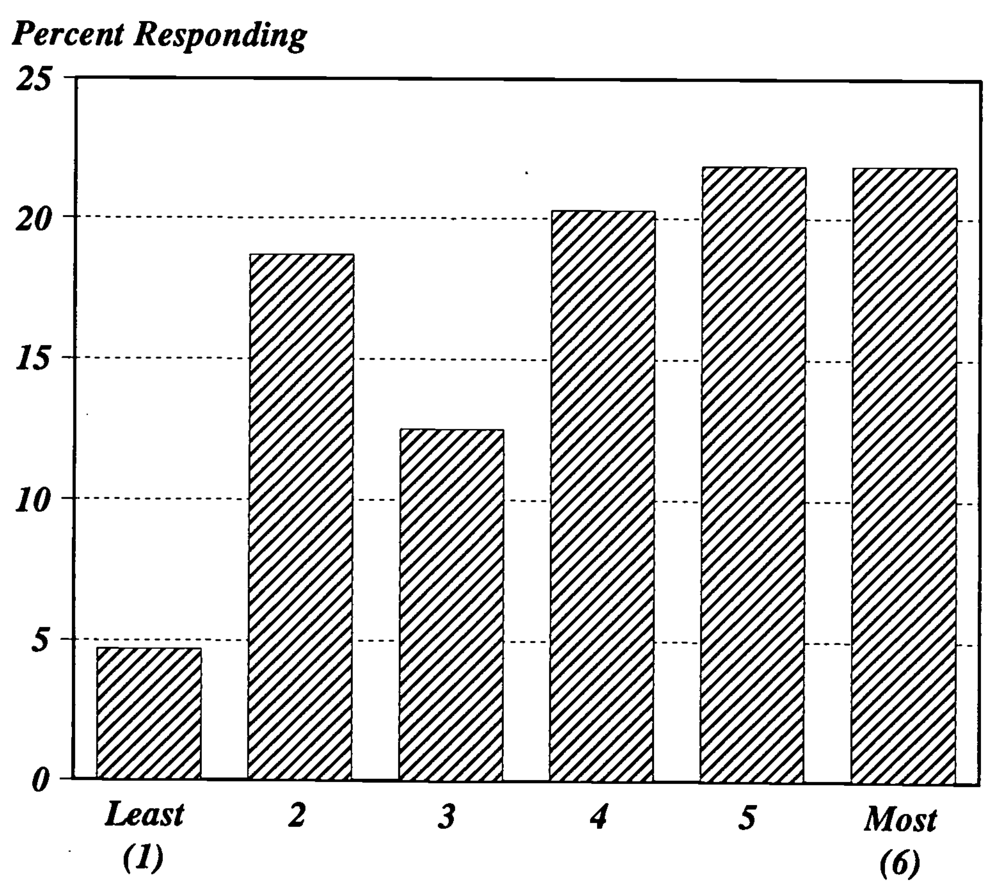

Percent Responding
50
40
30
20
10
0
1-3
4-6
>6
N/A
Size of Design Team


Percent Responding
90
80
70
60
50
40
30
20
10
0
Multi
Single
N/A
Disciplines on the Design Team

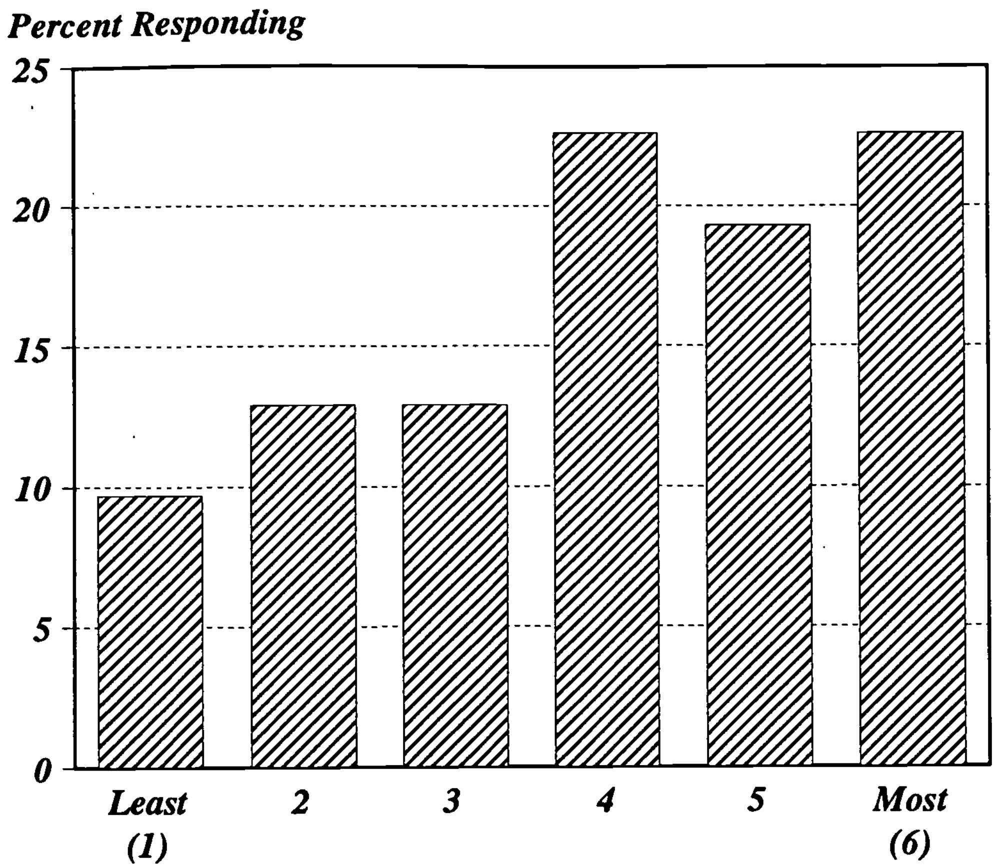
32



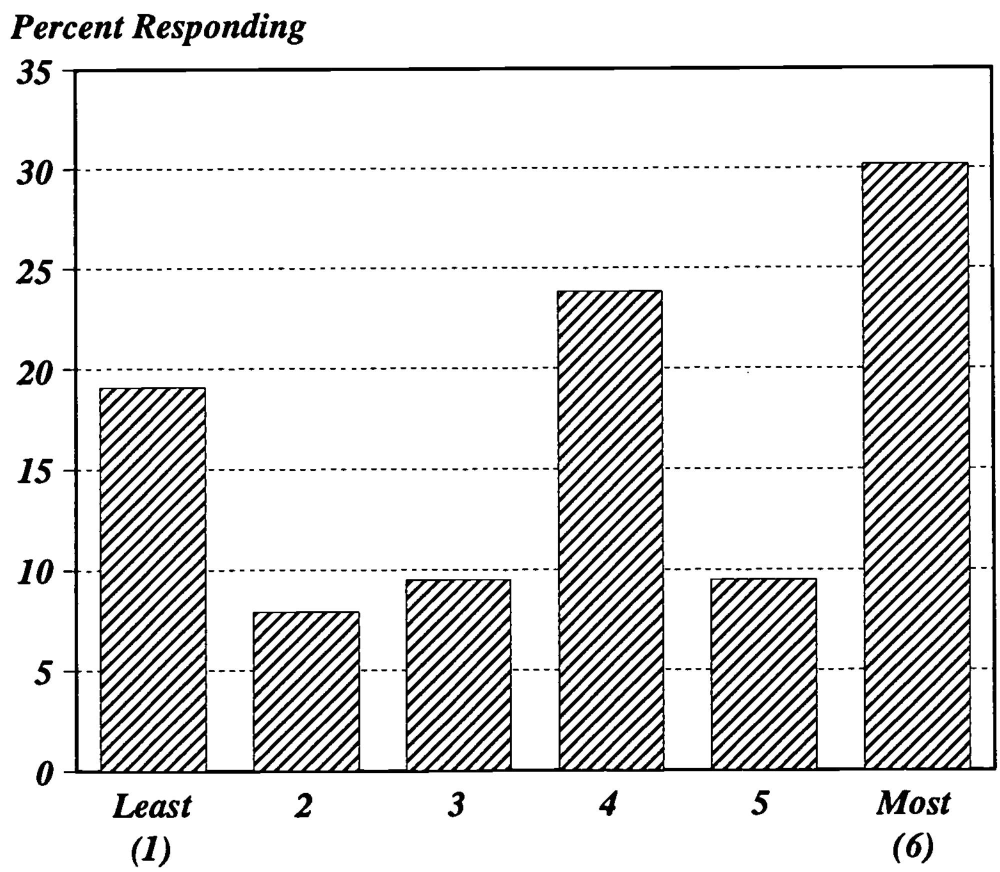
Importance of Technical Knowledge



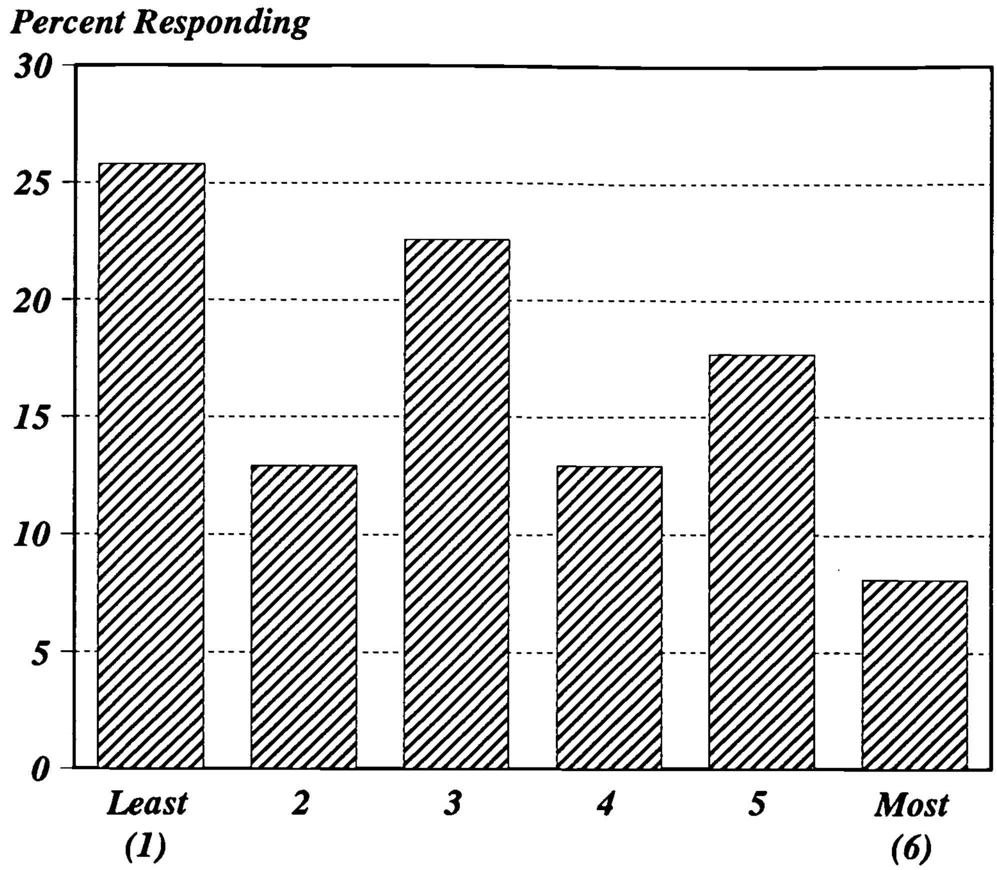
Importance of Communication Skills



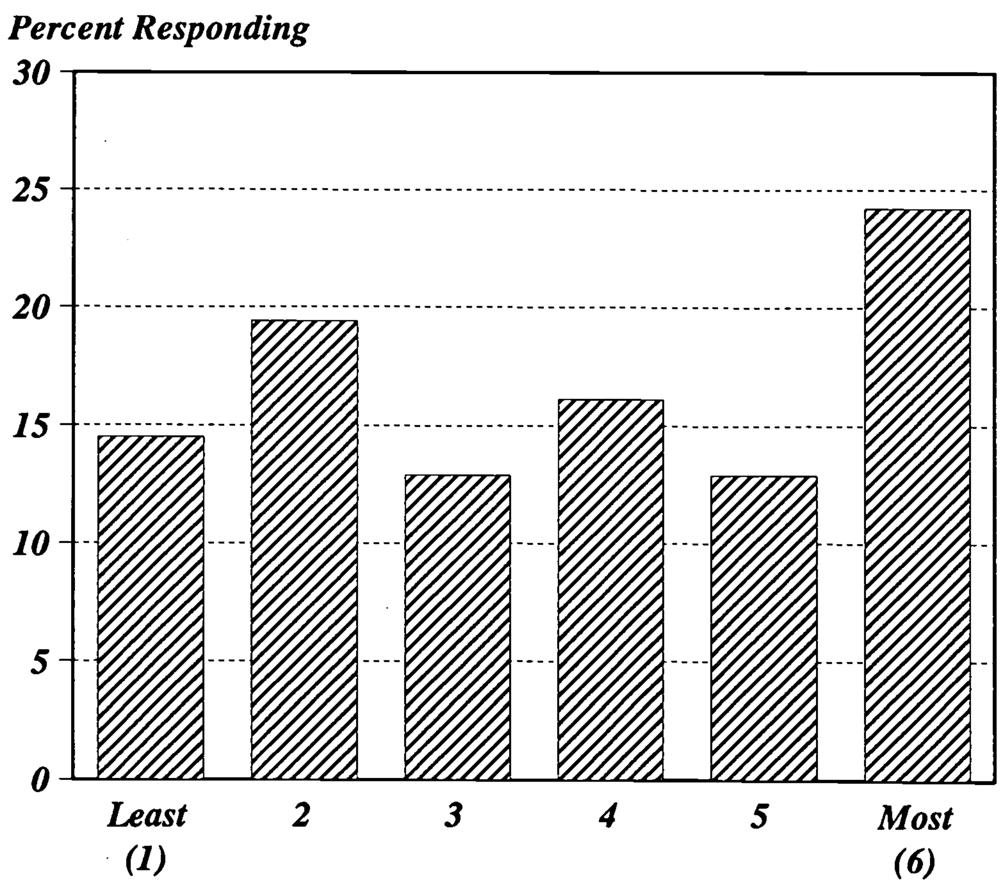
Importance of Interpersonal Skills



Importance of Self Education



Importance of Non-Technical Considerations



Importance of a Multidisciplinary Approach

Appendix B

Course Syllabi for First MSD Pilot Course (1990-91)
and
Second MSD Pilot Course (1991-92)

Colorado School of Mines
Multidisciplinary Senior Design Program

Course Syllabus
Fall Semester, 1990

Date	Lecture or Discussion Topic	Milestone
Aug. 23	Course organization; description of cliented projects; client letters distributed	Students choose projects; design teams formed
Aug. 30	Groups form and meet with their project manager; design notebook requirements	Design teams organize lab times and manager meetings
Sept. 6	Problem formulation and self-education; (design teams meet with their clients outside of class); memo and letter writing	Memo from group leaders describing each team's meeting schedule
Sept. 13	Time management; introduction to engineering design methodologies	Design teams prepare time lines
Sept. 20	Oral and written communications in the design process; continue discussing design methodologies	Clarification memo to client due
Sept. 27	Oral presentation describing each team's project plans	Oral presentations to design teams
Oct. 4	Proposal preparation	Client feedback to clarification memo
Oct. 11	Engineering analysis strategies	---
Oct. 18	Engineering analysis (cont.)	---
Oct. 25	Strategies for generating solution alternatives	---
Nov. 1	Work on project proposals; consultations with project managers and DMT	---
Nov. 8	Introduction to engineering ethics	Proposal drafts due
Nov. 15	Oral presentation describing team's proposals	Return proposal drafts with feedback
Nov. 22	Thanksgiving Break - no class; design teams meet as usual	Final proposals due
Nov. 29	Course and peer evaluations; prepare for progress reports and plan for spring semester	
Dec. 6	Oral presentations describing team progress	Oral and written progress reports

Course Syllabus for the Colorado School of Mines
Multidisciplinary Senior Design Program

Course Syllabus
Spring Semester, 1991

Date	Lecture or Discussion Topic	Milestone
Jan. 10	Recap first semester activities and accomplishments of each design team	---
Jan. 17	Review engineering design process	Revised timeline for spring semester with narrative
Jan. 24	Engineering synthesis strategies	memo report
Jan. 31	Introduction to liability and safety issues; human factors in design	---
Feb. 7	Liability and safety issues related to "cliented" projects; generate list of issues for projects	memo report
Feb. 14	Oral progress reports	Oral and written progress reports to DMT
Feb. 21	Guidelines for final oral and written reports	memo report
Feb. 28	Ethics and whistleblowing - I	---
Mar. 7	Ethics and whistleblowing - II	memo report
Mar. 21	Oral progress reports	Oral and written progress reports to DMT
Mar. 28	Sexual harassment and affirmative action in the professional environment	---
Apr. 4	Patent disclosure and application issues in engineering design	memo report
Apr. 11	Oral presentations of project solutions	Written draft reports to DMT
Apr. 18	No class - rehearsals of final presentations and demonstrations	---
Apr. 25	Public oral presentations and demonstrations of project solutions; course and peer evaluations	Oral and written final reports to clients
May 2	Final celebration!	---

Colorado School of Mines
Multidisciplinary Senior Design Program

Course Syllabus
Fall Semester, 1991

Week of	Lecture or Discussion Topic	Milestone
Aug. 19	Organizational meeting; description of cliented projects	Students choose projects; design teams formed
Aug. 26	Groups form and meet with their project manager; design notebook requirements; client letters distributed	Design teams organize lab times, manager meetings, and 1st client meeting
Sept. 2	Problem formulation and self-education; (design teams meet with their clients outside of class); memo and letter writing	*Memo due describing each team's meeting schedule
Sept. 9	Time management; introduction to engineering design methodologies	Clarification letters to client due
Sept. 16	Proposal preparation; continue discussing design methodologies	Project timelines due
Sept. 23	Oral presentation describing each team's project plans	Oral presentations to design teams; client feedback to clarification letters
Sept. 30	Engineering analysis strategies	*Progress reports due
Oct. 7	Strategies for generating solution alternatives	---
Oct. 14	No class - prepare proposal drafts	Proposal drafts due
Oct. 21	Oral presentation of proposals	Oral presentation of proposals to client
Oct. 28	Introduction to engineering ethics	Proposals due
Nov. 4	Ethical issues related to "cliented projects"	*Progress reports due
Nov. 11	Engineering synthesis strategies	Proposal feedback from DMT and clients
Nov. 18	Revision of proposals and timelines based on DMT and client feedback	Order materials needed for project work
Nov. 25	Thanksgiving - no class; design teams meet as usual	---
Dec. 2	Oral Presentations describing team progress	Oral and *written progress reports due

* individual assignments

Course Syllabus for the Colorado School of Mines
Multidisciplinary Senior Design Program

Course Syllabus
Spring Semester, 1992

Date	Lecture or Discussion Topic	Milestone
Jan. 16	Recap first semester activities and accomplishments of each design team; time management	---
Jan. 23	Review engineering design process	Revised timeline for spring semester with narrative; outline of final report
Jan. 30	Engineering synthesis strategies	---
Feb. 6	Introduction to liability and safety issues; human factors in design	---
Feb. 13	Oral progress reports	Oral and *written progress reports to DMT
Feb. 20	Liability and safety issues related to "cliented" projects; generate list of issues for projects	---
Feb. 27	Guidelines for final oral and written reports	---
Mar. 5	Ethics and whistleblowing - I	---
Mar. 12	Ethics and whistleblowing - II	
Mar. 26	Oral progress reports	Oral and *written progress reports to DMT
Apr. 2	Sexual harassment and affirmative action in the professional environment	---
Apr. 9	Patent disclosure and application issues in engineering design	Written draft reports to DMT
Apr. 16	Oral presentations of project solutions	
Apr. 23	No class - rehearsals of final presentations and demonstrations	---
Apr. 30	Public oral presentations and demonstrations of project solutions; course, peer, and self evaluations	Oral and written final reports to clients
May 7	Final celebration!	---

*individual assignment

Appendix C

Client Letters for MSD Projects
and
Executive Summaries and Tables of Content from
Student Design Reports

KOCH

KOCH ENGINEERING COMPANY INC

NEIL YEOMAN
DIRECTOR
TECHNOLOGY DEVELOPMENT

August 6, 1991

Dr. Ronald L. Miller, Associate Professor
Department of Chemical and Petroleum Refining Engineering
Colorado School of Mines
Golden, CO 80401

Dear Ron:

Confirming our discussion of August 5, 1991, Koch Engineering (KECI) would be pleased to participate in the program described in your letter of June 13, 1991 to Sonja Dadderio of Koch Materials.

As we discussed, the problem we would define is one of specific interest to KECI but one to which we have not been able to devote resources. We would therefore like to work reasonably closely with the student design team to maximize the benefit we would receive from participating in this activity. If possible, we would like to unofficially request that the results not be displayed outside of CSM.

We would like to address the use of vapor recompression in the fractionation of normal and iso-butane. This is a very complex problem and I am not sure your students will be able to put enough time on it to achieve all the results we would like but even partial completion would be of value to KECI.

In an industrial environment an advisor or supervisor would maximize initial input to minimize the project cost and schedule. Learning by those doing the work is not a normal consideration. In an academic environment you may wish to minimize the initial advisor input to maximize the learning that comes from thinking through a new problem from scratch. For the time being let me define the problem as the most cost effective production of a column distillate containing 99.5 percent iso-butane and a column bottoms containing 95.0 percent normal butane by distillation in a column being fed by 65,000 pounds per hour of a 55% i-C_4 / 45% n-C_4 stream and 35,000 pounds per hour of a 20% i-C_4 / 80% n-C_4 stream. The basic approach would be to establish the most cost effective vapor recompression design and compare it to an optimized design that uses a cooling water cooled condenser and a stream heated reboiler.

Under separate cover I am sending you five copies of Koch Engineering Bulletin KAL-10 which gives an overview of some of what KECI does. You and the students can use the tear-off cards to order any product literature you need (or want).

Sincerely

BEST COPY AVAILABLE

C-2

61 East 42nd Street • 31st Floor • New York, New York 10017-5610 • 212/682-5755
AX 212/661-4265 • TLX 424293 KOCHENG

Union Camp Corporation

5050 IRONTON, DENVER, COLORADO 80239 PHONE (303) 371-0760 FAX (303) 375-0718

August 5, 1991

Ron Miller
Chemical Engineering &
Petroleum Refining Dept.
Colorado School of Mines
Golden, CO 80401

Dear Ron,

Please accept this letter as our request to have a student design team work on a project at our Union Camp Denver plant.

The project will consist of designing a feed assist mechanism for one of our printing presses.

Both mechanical and electrical disciplines will be necessary to complete this project. Preliminary design scope is shown on the attached technical outline.

The project should culminate in the construction of a working prototype of the device, or a portion of the device.

We are anxious to begin working with your students this fall as our need for this mechanism is immediate.

We will be happy to met with the students to further explain the project.

Sincerely,

Len Owens

Lin Tiffany

TECHNICAL OUTLINE FOR S&S FEED MECHANISM

Requirement: Mechanical, electrical, pneumatic or hydraulic mechanism and controls to assist one or two men feed job. Job consists of lifting corrugated board in 20-30-pound bundles from a stack to the feed hopper. Feed rate averages 15 tons of material in each 8 hour shift - about 1.9 tons per hour. Sheet sizes will range in width from 14" to 50" and in length from 21" to 104".

Set-Up: The designed mechanism should be adjustable within the widths and lengths of board indicated above. Each set up should take no longer than 5 minutes to complete.

Components: As much as possible, the proposed design should use locally available, off the shelf components (conveyor, cylinders, lifts and programmable logic controller. Parts that need to be custom made should be designed for fabrication in either a local machine shop or in the plant maintenance shop.

Goal: Eliminate the need for lifting all board. One man may still be assigned to prepare loads and clear jams, but the mechanism should minimize lifting and bending hazards.

Proposal: Design team should submit at least two alternatives to solve this problem. The proposals should include drawings, bill of materials, estimated costs, installation instructions, and schedule for construction.

The second goal of Union Camp is to eliminate repetitive motion in feeding jobs. In addition, or in lieu of prohibitive costs in designing a feed mechanism, we might have individual start by submitting a design to build slapper bar to line up sheets (on Martin).

EG&G ROCKY FLATS

EG&G ROCKY FLATS, INC.
ROCKY FLATS PLANT, P.O. BOX 464, GOLDEN, COLORADO 80402-0464 • (303) 966-7000

September 13, 1991 WAA-023-91

The Corrosion Group
Colorado School of Mines
Golden, Colorado 80401

Dear Group Members:

At the Rocky Flats Plant, like most industrial operations, we have many corrosion problems. This means that a great deal of effort is expended in the protection of metallic components. Many of the people involved have no formal training in electrochemistry which is the basis for most corrosion protection activities.

I require a few teaching aids which clearly and succinctly demonstrate the appropriate electrochemical fundamentals involved in corrosion protection. These aids may be on the nature of corrosion cell potentials, electrode polarization, or a variety of corrosion protection principles. I will leave the specific choice of aids to you.

I look forward to meeting with you and discussing your ideas.

Sincerely,

W. A. Averill

W. A. Averill
Pyrochemical Technology
Building 779

cc:
W. D. Copeland

Solar Energy Research Institute
A Division of Midwest Research Institute

1617 Cole Boulevard
Golden, Colorado 80401-3393
(303) 231-1000

SERI

August 16, 1991

Professor John Trefny
Department of Physics
Colorado School of Mines (CSM)
Golden, CO 80401-1887

SUBJECT: Solar Vehicle Project

Dear John,

This letter is to document our conversations concerning SERI's continued commitment to acting as a "client" for a solar electric vehicle project under CSM's senior engineering design course. As the client, we will review and evaluate the project reports (oral and written) that the student project team prepares and possibly presents to us. I will act as the "principal investigator" for SERI. Attached, for consideration by you and the students in the engineering design course, are a letter for solicitation of a CSM project team and a draft description of the solar electric vehicle project that is open for discussion and review.

I understand the particular aspects of the design project will be decided by the student teams within the next few weeks. Once the students decide on their focus, planned objectives, and approach, I might then assist the project team to solicit other SERI staff who may want to volunteer their personal time to become involved in this project. For instance, SERI staff in the wind energy research area might offer fluid flow/modelling, or materials expertise. Other staff in the PV area may volunteer hands-on testing or characterization consultation. The project team could consider presenting a noon-time seminar at SERI.

Developing your senior engineering design course by providing substantive practicums involving "real-need projects" is an excellent method for invoking the student's creative potentials. I am looking forward to this opportunity to assist in your endeavors to provide a rewarding and hopefully exciting learning experience for the CSM student team members.

Sincerely,

T.S. Basso
Tom Basso
attachment

cc: T. Surek
J. Stone
J. Miller

d:\tsb\csmpv92.tsb

SOLAR ELECTRIC VEHICLE PROJECT DESCRIPTION (Draft, 8/24/90, Solar Energy Research Institute/Colorado School of Mines (SERI/CSM), Tom Basso, SERI Principal Investigator for Project)

SERI, through the Department of Energy, had become involved in assisting universities in participating in solar-powered car races, such as the GM Sunrayce USA competition (Figure 1). As an outgrowth, SERI is now assisting the Colorado School of Mines (CSM) with their Senior Engineering Design Course, through our client role as a solicitor for a motivated team to undertake a solar electric vehicle project.

The project is open to proposals for other than strictly solar racers; the American Tour de Sol had five categories of "solar" vehicles (Table 1). The CSM project team members will have this same freedom in proposing the scope of their project. The project team must submit a proposal that fully defines the project. This includes developing the rules to govern their project operations, such as the GM Sunrayce competition required the description of the project's organization, its funding and resources, and the selection/decision-making process (e.g., provide business plans as well as technical plans). The project should last two or three years. The focus should be on the current year but documentation should address outlying years. As the team is developing their proposal, and at their request, T. Basso could solicit other SERI staff who may want to volunteer their personal time to become involved in this project. For instance, SERI staff in the wind energy research area might offer fluid flow/modeling, or materials expertise. Other staff in the PV area may volunteer hands-on testing or characterization consultation.

Figure 1. SOLAR RACE CAR TECHNOLOGY [1]

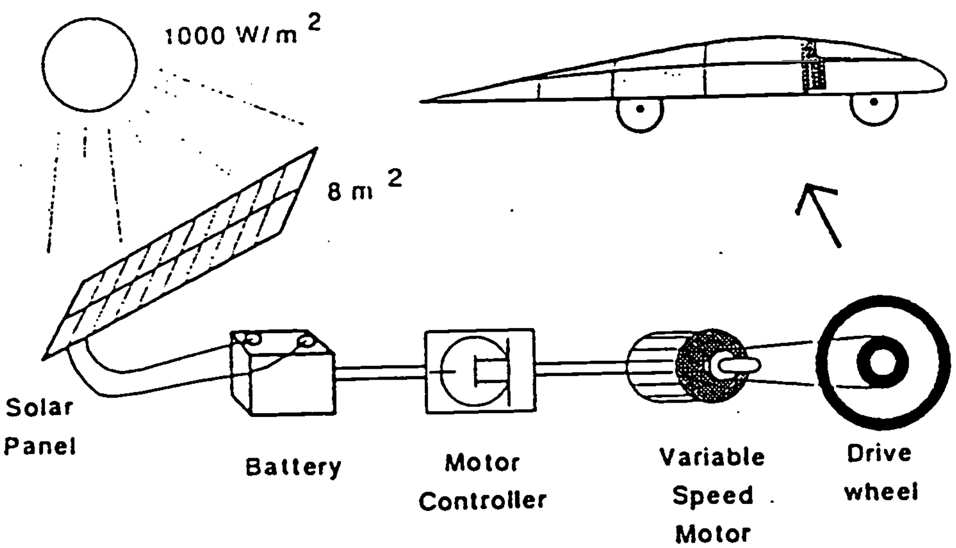


Table 1 [2] Five vehicle categories

1. **Commuter:** A practical two to four seater vehicle which travels at normal road speeds (35–55 mph) and has a driving range of at least 50 miles before recharging.
2. **Tour de Sol Racing:** Vehicles designed to travel long distances at speeds of up to 65 mph with a driving range of over 100 miles.
3. **Cross-Continental:** Vehicles designed to travel long distances at low road speeds throughout the day.
4. **Innovative Storage:** Vehicles using new storage technologies, such as hydrogen fuel-cell.
5. **Open:** Vehicles that conform to the aims of the event but do not fall into an existing category.

The Tour de Sol Racing and Cross continental vehicles must recharge their batteries exclusively from the sun, through the use of photovoltaic cells mounted on the car. Commuter cars can also be recharged from the grid, assuming that the electricity could have been generated by photovoltaics at home or some other location.

Potential Contacts

- o CSU (GM Sunrayce entrant), Public Relations Office (1-491-1525)
- o Richard King, DOE (GM Sunrayce cosponsor, European Tour de Sol observer) (202) 586-1693
- o General Motors Corporation, General Motors Building - Room 11-30, Detroit, MI, 48202
- o Northeast Solar Energy Association (American Tour de Sol) NESEA (802) 254-2386
- o World Solar Challenge; P.O. Box 290; Bribie Island, Qld. 4507; Australia (perhaps ask above contacts for further Australian information)

References

1. Official Program -- GM Sunrayce USA
2. NESEA American Tour de Sol information sheet.

UNITED STATES DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
[formerly National Bureau of Standards]
325 Broadway
Boulder Colorado 80303-3328

Reply to the attention of: 583.10

23 August, 1990

Dr. Ronald L. Miller
Chemical Engineering and Petroleum Refining Department
Colorado School of Mines
Golden, CO 80401

Dear Dr. Miller:

It is a pleasure to forward to you our two-page description of a multidisciplinary design project, "Automated Microcrystallizer". I am eager to work with students in the interdisciplinary design program on this project. You will be pleased to know that this concept received a "R&D100" award for 1990, so it is a worthy project with a meaningful future.

I will be pleased to provide guidance as the project progresses and to make an introductory presentation of the background, concept and expectations of the design. There is room for a certain amount of flexibility, and we are already considering an augmentation to the sensor system -- a conductivity sensor that has been tested on a prototype in our laboratory.

Please feel free to call upon me as the time approaches to meet with the class and/or arrange to communicate with students on the project. I look forward to a productive interaction.

Sincerely,

Paul Todd

Paul Todd
Transport Processes Group 583.10

AUTOMATED MICROCRYSTALLIZER

P. Todd
Chemical Engineering Science Division
NIST

Introduction

Drug designers and protein engineers use three-dimensional structure data from biological macromolecules (proteins, nucleic acids) to guide the development of modern pharmaceuticals. The entire process of molecular structure determination has been automated except the growing of the crystals required for study. Typically, a single crystal about 1 mm (or a little less) on a side is required for x-ray diffraction study, and structural ordering (faithful repeat distances) around 0.2 nm are desired. It is therefore necessary to automate the growth of crystals from several micrograms of dissolved material under conditions that prevent the formation of lattice irregularities.

Objective

Design a 10-position macromolecule crystallizer using osmotic dewatering (a patented technique) through a reverse osmosis membrane with active control over the rate of water removal based on two-angle light scattering.

Project Description

A circular or linear array of osmotic dewatering cells with optically smooth windows is monitored by a collimated beam of light (laser, for example) that passes through each cell and is detected at two scattering angles. A computer records the ratio of light intensities at the two angles, thereby estimating the particle size distribution as precipitation and nucleation commence. This signal is used to control the concentration of salt in the lower half of each cell. Each cell consists of an upper half, in which crystallization occurs and from which light scattering is measured (volume of about 0.2 ml), and a lower half, which contains a salt solution that draws water out of the upper half by osmosis. The computer controls the salt concentration in the lower half by injecting water or concentrated salt under algorithmic command. General diagrams are attached.

Alpha Optical Systems, Inc.
A Coors Ceramics Company

P.O. BOX 669 • 1611 GOVERNMENT STREET
OCEAN SPRINGS, MISSISSIPPI 39564
TELEPHONE 601/875-0211
FACSIMILE 601/875-6708

23 August 1990 Refer to: C90.336.DWR

Colorado School of Mines
Golden, Colorado 80401

Attention: Dr. Gerry Martins
Department of Metallurgical & Materials Engineering

Dear Dr. Martins:

Transparent polycrystalline $MgAl_2O_4$ Spinel a very hard, erosion resistant, thermally and chemically stable isotropic optical material is in increasing demand for advanced weapons and aerospace optical systems. The raw material, spinel powder, is an important ingredient in successful fabrication of high quality Spinel ceramic. There is a need for a cost effective, reproducible, domestic powder source.

The Colorado School of Mines has developed a potentially very attractive powder preparation method using alkoxide technology. There is a need to design, build, and demonstrate equipment for producing Spinel powder using the technology which has been demonstrated on a laboratory basis. The cost for producing powder, in quantities of 10,000-20,000 pounds per year should be calculated. The following properties of the delivered powder must be monitored and controlled:

- stoichiometry
- purity
- particle size
- surface area
- crystal structure

Please advise me of your level of interest and the timing for initiating and completing such a program.

A milestone outline is attached.

Sincerely,
ALPHA OPTICAL SYSTEMS, INC.

Don W. Roy
Vice President, New Product Development

G10

Alpha Optical Systems, Inc.

PROJECT MILESTONES

1.0 PROGRAM PLAN AND SPECIFICATION REFINEMENT

2.0 PRELIMINARY DESIGN PACKAGE

- Scope of Work
- Process Flow Diagram
- Process Control Steps
- OSHA Requirements
- Cost Proposal
- Schedule

3.0 DETAILED DESIGN AND PROCUREMENT

- Equipment Specifications
- Material Specifications
- Drawings
  - Chemical Processing
  - Plumbing
  - Electrical
  - Process Control
  - Information Processing

4.0 FACILITY INSTALLATION

5.0 STARTUP AND TESTING

6.0 ACCEPTANCE

CIFER

Colorado School of Mines
Golden, Colorado 80401-1887
303/273-3650

August 15, 1990

Dr. Nigel Middleton
Dr. Ronald L. Miller
Colorado School of Mines
Golden, CO 80401

Dear Sirs:

The Colorado Institute for Fuels and High Altitude Engine Research (CIFER) is presently designing and installing test equipment in our Fuels laboratory located on the CSM campus. CIFER has need for a multidisciplinary design team to complete a project requiring expertise in mechanical, electrical, and chemical engineering.

CIFER has aquired a partially complete CFR-type variable compression octane testing engine fitted with an eddy current dynamometer from the Solar Energy Research Institute (SERI) in Golden. The unit needs to be installed with new instruments, controls, a cooling system, and fuel supply system so that one cylinder testing of gasoline and diesel fuels can be performed. The overall project objectives will be to: 1) complete necessary process, mechanical, and electrical designs, 2) procure necessary hardware components, 3) install, startup and test the completed engine system. CIFER staff will available to assist the design team with each of these objectives.

Attached is a short list of milestones for this project. Please advise me of your level of interest in the proposed program.

Sincerely yours,

Michael S. Graboski
Director, Colorado Institute for Fuels
and High Altitude Engine Research

Project Milestones

1.0 Scope of Work and Acceptance Criteria

2.0 Preliminary Design Package

- Design scope of work
- Process flow diagram
- P&ID
- Mechanical, electrical, and I&C specifications
- Cost proposal
- Schedule

3.0 Detailed Design and Procurement

- Equipment procurement specifications
- Material procurement specifications
- Piping drawings
- Electrical drawings
- Control drawings
- Computer data logging schematics

4.0 Installation (by CIFER personnel under direction of design team)

5.0 Startup and Testing (by CIFER personnel under direction of design team)

6.0 Acceptance (based on agreed upon testing criteria)

Solar Energy Research Institute
A Division of Midwest Research Institute

1617 Cole Boulevard
Golden, Colorado 80401-3393
(303) 231-1000

SERI

August 24, 1990

Professor John Trefny
Department of Physics
Colorado School of Mines (CSM)
Golden CO, 80401-1887

SUBJECT: Solar Electric Vehicle Project

Dear John,

This letter is to document our conversations concerning SERI's commitment to assisting the Colorado School of Mines with their Senior Engineering Design Course, through our role as a "client" searching for a motivated team to undertake a solar electric vehicle project. For this project, we are hoping to find enthusiatic, self-starting engineers and scientists to participate in the growing opportunities mandated by the multidisciplinary R & D problems associated with solar-electric vehicles. Attached is a draft project description that is open to discussion and revision.

As the "client", SERI -- the nation's lead laboratory for solar and renewable energy research and development - has the need for a top-flight engineering project team. The need is to expand the frontiers of solar transportation, by providing design solutions for overcoming technical constraints to further development of cost-competitive electric vehicles. We are looking for an assertive, responsive team to take charge and focus themselves in defining a high payback project, planning their approach, and executing the tasks. By the spring of 1991, the team should deliver fruitful results that their successors will build on. The project should take two to three years to reach a practical stopping point. Each school year should conclude in achieving significant milestones, including some hardware design/development as well as increased knowledge in the field of electric vehicles.

During the project, we at SERI and at CSM must be kept closely informed of the ongoing progress through written technical reports and skillful presentations to our technical and management decision-makers. The successful outcome of this project hinges on the dedication and engineering expertise of the winning project team.

I am looking forward to this opportunity to work with CSM engineers and scientists to make a positive and hopefully mutually rewarding contribution to the field of solar electric vehicle technology.

Sincerely,

Tom Basso

T. S. Basso
Staff Scientist
Photovoltaic Program Branch

attachment (draft project description)

Fractionation Column Design for Normal and Iso-Butane Mixtures

Prepared for: Mr. Neil Yeoman
Director, Technology Development
Koch Engineering Company, Inc.
161 East 42nd Street, 31st Floor
New York, New York 10017

Prepared by:

Gwen Barthel
Andy Dieball
Hans Hoppe
Cindy Licko
Gregg Nyberg

Koch Engineering Team
Colorado School of Mines
Golden, CO 80401

May 13, 1992

Executive Summary

The purpose of this project is to develop the most cost-effective design for fractionating normal and iso-butane. We examined two methods of distillation to accomplish this process: a traditional design with a condenser and reboiler, and a vapor recompression design, which utilizes a compressor and one heat exchanger. A total of five different columns were designed, three traditional columns and two vapor recompression columns. We designed these columns using a simulator package called HYSIM, and refined the column sizes using the Koch Tower Design software package.

After the five designs were completed, we calculated the cumulative cost of each column over a ten year project life. Both capital and operating costs were considered. We found that the energy requirements of the columns dominated the project economics. Although the traditional columns had considerably lower capital costs due to the large compressor cost for the vapor recompression design, the vapor recompression columns had a lower cumulative cost over the ten year project life due to lower energy requirements. Our conclusion is that the 75 tray vapor recompression column is the most cost effective column of our five designs.

Our analysis only compared columns utilizing valve tray column internals. Many other types of column internals could have been considered (e.g. random packing, structured packing), but due to time constraints we only considered tray columns.

Table of Contents

List of Figures.....ii

List of Tables.....iii

Introduction.....1

Conclusions and Recommendations.....3

Effects of Energy on Column Design.....5

Process Analysis.....6

Traditional Column Design.....6

Operating Conditions.....7

HYSIM Procedure.....7

Results.....8

Vapor Recompression.....9

Operating Conditions.....10

HYSIM Procedure.....10

Results.....12

Auxiliary Equipment.....12

Pressure Vessel Design.....13

Economic Analysis.....15

References.....18

Appendix A. Process Analysis Results.....19

Appendix B. Equipment Summary and Process Flow Diagrams.....49

Appendix C. Auxiliary Equipment Design Sample Calculations.....57

Appendix D. Pressure Vessel Design Sample Calculations.....61

Appendix E. Pressure Vessel Schematic Diagrams.....71

Appendix F. Economic Analysis Tables.....87

List of Figures

Figure 1. Schematic of a traditional distillation column................................2

Figure 2. Schematic of a vapor recompression distillation column....................2

Figure 3. Comparison of cumulative column cost for traditional design versus vapor recompression (most economical cases)...............................4

Figure 4. Process flow diagram used for vapor recompression computer simulations...11

List of Tables

Table 1. Summary of traditional distillation column simulation results.............9

Table 2. Summary of vapor recompression distillation column simulation results...12

Table 3. Summary of total fixed capital investment, annual operating costs and total cumulative cost over the ten year project life (in thousands of dollars)...17

Design of Corrugated Board Bottom Prefeeder
for
Mr. Len Owens, Manufacturing Manager
of
Union Camp Corporation, Container Division
Denver, Colorado

Prepared by:

Colorado School of Mines Design Team

Kregg Hyer
Mark Morgan
Dan Nelson
John Strobel

May 7th, 1992

EXECUTIVE SUMMARY

This document is being presented to Union Camp Corporation, Container Division, and specifically to Mr. Len Owens, Manufacturing Manager, with the purpose of providing an outline of this design project. Within this document, we provide Union Camp with all information pertinent to the prefeeder design, construction, operation, evaluation, and maintenance.

The task we have undertaken involved developing a bottom prefeeder design which will feed stacks of cardboard blanks into an S&S press. This prefeeder must also meet a specified list of objectives and functional requirements, while at the same time operating within the designated set of constraints. The modes of operation of the prefeeder design are explained in detail in the technical portion of this document. From this detailed technical plan, we provide enough information on the operational characteristics of the design to enable Union Camp to accurately visualize this design's operation.

Also included in this document is a management plan which briefly presents each group member's qualifications and experiences which make him suited for this design project. A brief description of the facilities and equipment necessary for fabrication of the design is also included. In addition, this document contains a complete set of parts lists, parts drawings, and sample catalog listings to facilitate parts acquisition and fabrication. Assembly drawings and assembly directions are also

included to facilitate machine construction.

Finally, we detailed the methodology which should be used in evaluating the performance of our design once construction is complete. This methodology involves an extensive series of tests which allow for evaluations of the design's success in meeting the functional requirements, as well as those concerning safety and ease of use.

TABLE OF CONTENTS

EXECUTIVE SUMMARY i

INTRODUCTION 1

PREFEEDER DESIGN 3
- Lift Description 3
  - Assembly Information 5
  - Maintenance 6
- Conveyor and Tapper Description 6
  - Conveyor and Tapper Assembly Information 7
    - Drawing Numbers 7
    - Assembly 8
    - Operation 10
    - Recommendations 10
    - Budget 11
- Power and Controls Description 12
  - Control System Model 18
    - Introduction 18
    - Description 18
    - The Model 19
    - Model Objectives 20
    - Model Results 20

DESIGN TEAM 22

DESIGN EVALUATION 24

BUDGET 28

CONCLUSION 29

Appendices

Appendix 1 - Lift Parts List

Appendix 2 - Lift Drawings

Appendix 3 - Conveyor and Tapper Parts List

Appendix 4 - Conveyor and Tapper Drawings

Appendix 5 - Power and Controls Parts List

Appendix 6 - Power and Controls Drawings

Corrosion Demonstration Package for

Education on Corrosion Basics

Prepared for: Dr. William Copeland
Director, Materials Science Department
Colorado School of Mines
Golden, CO 80401

Prepared by:

Bill Beltz
Bob Herbon
Teresa Spelts
Randy Sulte
Ken Warn

Corrosion Demonstration Team
Colorado School of Mines
Golden, CO 80401

7 May 1992

EXECUTIVE SUMMARY

Corrosion is a problem in nearly every industry. Not only are corrosion concerns costly, but they are also potentially extremely damaging both to humans and to the environment. People lacking a technical background in corrosion must merely understand the rudiments of corrosion in order to realize that this danger must be minimized from both an economic view and an ethical view. To meet the need to educate people on the basics of corrosion, the Corrosion Demonstration Design Team was given the task of developing a corrosion demonstration package. Therefore, the team created a slide show demonstrating basic corrosion principles using several working models developed by team members. These models are identified according to corrosion type:

1. Concentration Cell Corrosion
2. Dissimilar Metal Corrosion
3. Stray Current Corrosion
4. Erosion-Corrosion

A fifth type of corrosion was identified as differential temperature corrosion, but a working demonstration model of this corrosion type was not developed due to budget and time constraints. Although this fifth corrosion concern is addressed in the demonstration slide package, it is not discussed in this report. The background information, equipment requirements, procedure, and a discussion of results are presented for each corrosion demonstration model according to type.

TABLE OF CONTENTS

EXECUTIVE SUMMARY i

TABLE OF CONTENTS ii

LIST OF FIGURES iii

LIST OF TABLES iv

INTRODUCTION 1

CONCENTRATION CELL CORROSION 5

Introduction 5

Equipment 7

Experimental Procedure 8

Discussion of Results 9

Conclusions 11

DISSIMILAR METAL CORROSION 12

Abstract 12

Equipment 13

Experimental Procedure 14

Discussion of Results 14

Conclusions 15

STRAY CURRENT CORROSION 16

Abstract 16

Equipment 16

Experimental Procedure 16

Discussion of Results 17

Conclusions 17

EROSION-CORROSION 18

Abstract 18

Equipment 18

Experimental Procedures 19

Discussion of Results 21

Conclusion 22

BIBLIOGRAPHY 23

LIST OF FIGURES

Figure 1. Open Circuit Dry Cell

Figure 2. Short Circuited Dry Cell

Figure 3. Metal Surface Local Action Cell

Figure 4. Salt Concentration Cell

Figure 5. Differential Aeration Cell

Figure 6. Wet-Splash-Dry Cell

Figure 7. Salt Concentration Versus Corrosion Rate

Figure 8. Oxygen Concentration Versus Corrosion Rate

Figure 9. Concentration / Aeration Cell

Figure 10. Dissimilar Metal Flow System

LIST OF TABLES

Table 1. Relative Electrochemical Potentials

Table 2. Initially Planned Test Conditions

Table 3. Values of Variables

Table 4. Final Test Conditions

Table 5. Weight Losses in Pipes

SOLAR ELECTRIC VEHICLE (SEV) PROJECT

Solar Electric Vehicle Project
for the
Colorado School of Mines

Prepared by:
The Multidisciplinary Senior Design
Solar Electric Vehicle Project Team:

Jo Brown
Scott Burdick
Calvin Feik
Jeanne Fermelia
Adam Rompage

Prepared for:
Design Management Team:

Dr. Ronald L. Miller
Dr. Barbara M. Olds
Dr. John U. Trefny

May 7, 1992

EXECUTIVE SUMMARY

In the interest of new technology, environmental concern, and energy awareness, the Colorado School of Mines is designing and building a solar-powered race vehicle. A team of five senior level students was chosen to manage the project and has been working toward the final design and construction of the vehicle. This is the second year of a multi-year undertaking in which current members of the design team have taken over where last year's team left off. The students involved are educated in different disciplines, all of which contribute a unique part to the design and implementation of the vehicle.

Many design considerations have been evaluated regarding the optimally efficient approach to building a solar powered race vehicle. The project has been divided into several areas, each being a key factor in the overall effectiveness of the car. These areas include: photovoltaic cells, batteries, motor/motor controller, chassis, steering, suspension, braking, and aerodynamics.

Solar cells, batteries, motor, and motor controller will constitute the major expenses. The vehicle will also include a high efficiency, permanent magnet, brushless DC electric motor. The chassis of the car will be an aluminum space frame consisting of thin walled aluminum tubes connected at nodes by aluminum fasteners.

The design will be constructed in several steps. The chassis will be the first component constructed, followed by the suspension, braking, and steering assemblies. From this point, the internal motor and batteries can be added yielding a drivable vehicle. The next phase will involve the attachment of body panels and the solar array.

This project will continue beyond the 1991-92 school year, when new selections of seniors will complete the vehicle. Through these periods, the design will be revised and modified where needed to obtain the most effective design to represent the Colorado School of Mines.

TABLE OF CONTENTS

INTRODUCTION 1

BACKGROUND 2
PROJECT ADMINISTRATION 2
EPICS STUDENTS' INVOLVEMENT 4
PROJECT FACILITIES 5
FUNDRAISING AND BUDGETING 5

DESIGN AND ENGINEERING / COMPONENT DEVELOPMENT AND SELECTION 7

MECHANICAL SYSTEMS DESIGN 7
CHASSIS 7
BRAKING SYSTEM 11
STEERING SYSTEM 12
SUSPENSION SYSTEM 13
DRIVETRAIN 15

AERODYNAMICS SYSTEMS DESIGN 16
INTERNAL AIRFLOW 16
EXTERNAL AIRFLOW 19

ELECTRICAL SYSTEMS DESIGN 21
STUDENT STUDIES 20
SOLAR POWER SUPPLY 22
PROPULSION SYSTEM 25
OTHER ELECTRONICS 28

REFERENCES 32

APPENDICES 33

Design, Construction and Operation of an Automated Multi-Cell Protein Microcrystallizer

Colorado School of Mines

1 May 1991

Student Design Team
Dorena Barnes
Danny Frederick
Penny Iwamasa
Jeffrey Ranney
Scott Thornburg

Client
Dr. Paul Todd
Transport Process Group 583.10
Chemical Engineering Science Division
United States Department of Commerce
National Institute of Standards and Technology
325 Broadway
Boulder, CO 80303-3328

EXECUTIVE SUMMARY

The objectives of this project are to design a system to automate and monitor the growth of protein microcrystals in multiple cells, to construct a single-cell prototype based on the multi-cell design, and to provide documentation for the completion and expansion of the single-cell microcrystallizer to a multi-cell system. Design of the multi-cell system, including equipment specification, has been completed. A single-cell prototype has been partially constructed and tested. The cell, flow system, cooling system, and preliminary computer control system and software programming has been completed. The remainder of the system can be completed upon receipt of the remaining control and optical equipment. This document is the culmination of the student design team's efforts and includes text describing each of the above objectives.

The design described herein uses osmotic dewatering, a method developed at NIST, to grow large quantities of high-quality protein crystals in an automated system capable of controlling several different cells simultaneously.

Each cell has an independently controlled reservoir of salt-water solution. The process incorporates an active-flow system in order to increase response time in salt concentration changes in the cell reservoirs. The flow system passes the salt solution below the reverse osmosis membrane, the interface between the upper growth cell and the lower dewatering reservoir. The concentration gradient across the membrane provides an environment for water to flow from an area of higher water concentration (in the cell; above the membrane) to an area of lower water concentration (beneath the membrane). To achieve optimal crystal growth, each reservoir is maintained at approximately 18 °C by a cooling bath flow system and by a cooling plate, which in turn maintain the individual cells at the same temperature.

Two-angle light scattering analytically determines relative particle size and population in the crystal-growth cell. The computer system determines if a concentration change is necessary to continue crystal growth based on measured light-scattering data.and if so, adds salt-water solution or pure water to the growth cell reservoir by opening and closing the appropriate solenoid valves in the flow system for a prescribed period of time. All concentration changes are made gradually to prevent protein showering, the undesirable growth of many small protein crystals.

TABLE OF CONTENTS

		Page
Executive Summary		i
List of Figures and Tables		iii
Introduction		1
Problem Statement		1
Accomplishments		1
Advantages of Crystallization Process		2
Past Crystallizing Experiments		3
Design Basis		5
Technical Plan		6
General Design Description		6
Cell Design		9
Laser and Mirror System		11
Dewatering and Concentration Control		12
Data Acquisition & Control System		14
Mixing and Temperature Control		16
Vibrational Stability		17
Cost Analysis		18
Project Evaluation & System Description		19
Future Design Considerations		26
Future Work on the Optical System		26
Software Development Procedure		27
Cost Analysis		29
Conclusion		30
References		31
Appendix A	Initial Client Letter	32
Appendix B	Design Team Resumes	36
Appendix C	Calculations for Acceptability of a Sealed Cell	42
Appendix D	Laser Intensity Requirement Calculations	47
Appendix E	Estimation of Lag Time in Stagnant System	52
Appendix F	P&ID - Two-cell System	58
Appendix G	Valve Control Program	61

LIST OF FIGURES AND TABLES

		Page
Figure 1	NIST Single Cell Design for Protein Crystal Growth	4
Figure 2	Flow Diagram for a Single Growth Cell	7
Figure 3	Laser Measurement System	8
Figure 4	Schematic of Cell	9
Figure 5	Dewatering Process	12
Figure 6	Computer Control System	14
Figure 7	Photograph: One Cell Prototype	20
Figure 8	Photograph: The Cell	21
Figure 9	Photograph: Flow System	22
Figure 10	Photograph: Mixing and Injection System	23
Figure 11	Photograph: The Computer Control	24
Figure 12	Photograph: Relay Board	25
Figure 13	System Flowchart	28
Table I	Cost Analysis for a Single-Cell System	18
Table II	Cost Analysis for an Eight-Cell System Expansion	29

FINAL PROJECT REPORT

SUBMITTED TO:

ALPHA OPTICAL SYSTEMS, INC.
Mr. Don Roy
Vice President, New Product Development
1611 Government St.
Ocean Springs, MS 39654

Submitted By:
Colorado School of Mines Multidisciplinary Senior Design Team
Golden, CO 80401

Title:
THE MANUFACTURE OF A SPINEL POWDER BY THE GAS PHASE HYDROLYSIS OF A DOUBLE ALKOXIDE

Dina Svaldi Bauer
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MAY 2, 1991

EXECUTIVE SUMMARY

Our multidisciplinary design team, part of a pilot program at the Colorado School of Mines which combines students and faculty from different academic departments, has designed, modified, and operated an existing bench scale unit for the production of spinel powder. Spinel powder is an advanced polycrystalline ceramic which is used for the production of optical elements. These optical elements have special transmittance properties, combined with exceptional hardness and strength, as well as unique chemical and thermal properties. Spinels are preferable to glass because they are 4 to 5 times as strong and are much harder. Alpha Optical Systems Inc. tested samples of glass and spinel by sandblasting each sample with coarse sand for five minute intervals. The spinel sample showed no surface abrasion, but the glass sample was very pitted.

The spinel powder used by our client, Alpha Optical Systems, is currently purchased from France where it is made by using an organic process. Our objective was to prove that the gas phase hydrolysis process for the production of spinel powder developed at the Colorado School of Mines is a viable alternative to the overseas source. The gas phase hydrolysis process would be free of the sulfur impurities which occur in the present source, and would alleviate national defense concerns because of its domestic availability.

We modified an existing bench scale unit to produce a high purity $MgAl_2O_4$ spinel powder with particle sizes from 0.1 to 1.0 micron. The powder was then crystallized and hot pressed into an

optical lens. Hot pressing is a process where the powder is heated while pressure is applied.

The powder was successfully hot pressed into a lens but this lens was slightly opaque. This opaqueness was related to an excess of aluminum, and E.D.S. (Energy Dispersive Spectroscopy) was used to determine the powder stoichiometry. The E.D.S. test indicated that the powder was 10 percent aluminum rich and that no impurities were found in the powder. Had time permitted, we would have mixed our own alkoxide. We feel that the alkoxide solution was contaminated or possessed incorrect stoichiometry, thus affecting the stoichiometry of the final powder.

Our work was based on graduate work performed in the Colorado School of Mines Metallurgy Department. Work on the spinel powder was first undertaken by Carole Grauss, a PhD student, then by Karen Phillips, an MS student who recently completed her thesis work. Our design was predominantly based on the gas phase hydrolysis approach which Karen Phillips developed with the aid of Dr. Gerry Martins, our technical advisor in the Metallurgy Department. Our design includes an air compressor, air dryer, air heater, steam generator, aerosol generator, hydrolyzer, cyclone, refrigeration system, Weber cyclone, and oven.

The gas phase hydrolysis process can produce a spinel powder with precise stoichiometric control and very high purity. Our design group recommends continued efforts with this method of powder production. We feel that further experimentation would allow for fine tuning of the ratio of magnesium and aluminum alkoxides, and adjustments in particle size. This high purity, custom-designed spinel powder would theoretically allow Alpha Optical Systems to produce larger and more perfect optical lenses.

TABLE OF CONTENTS

Section	Page
EXECUTIVE SUMMARY	i
INTRODUCTION	1
RESULTS AND MODIFICATIONS	4
RECOMMENDATIONS	11
REFERENCES	13
APPENDICES	14

LIST OF FIGURES

Page

Figure 1: Photograph of Bench-Scale Unit 3

Figure 2: Process Flow Diagram 5

Figure 3: Energy Dispersive Spectroscopy (EDS) Results 7

Figure 4: Scanning Electron Microscope (SEM) Results 9

LIST OF APPENDICES

		Page
A)	Start up Procedure	14
B)	Equipment Specifications	16
C)	Precursor Costs	17
D)	Resumes	18
E)	Technical Background (from proposal)	24
F)	Technical Plan (from proposal)	27
G)	Costs Incurred	38
H)	Flow Rates and Material Balance Calculations	39

Development of a Fuels Testing Facility Based on a CFR Engine

Project
for
Dr. Mike Graboski
Director of
Colorado Institute for Fuels
and High Altitude Engine Research

Multidisciplinary Senior Design
May 3, 1991

Don Cameron -- CR
Holly Sprackling -- EE
Martin Supitar -- EE
Tanya ten Broeke -- ME
Don Wojciechowski -- ME

PROJECT GOALS:

OBJECTIVES:

The objective of this project was to design, install, and test a fuel testing platform capable of researching all aspects of various fuels as a function of engine speed and load. Our design team was presented with a 1951 Cooperative Fuel Research engine to refurbish and renovate into a modern testing platform.

The engine, as we received it, was in critical condition. It had been in storage for over ten years, and its operational status was unknown. The engine needed a fuel induction system, a cooling system, an exhaust system, electrical monitoring, and controls. The dynamometer was also in marginal condition. The dynamometer cooling system, except for the two cooling chambers, was non-existent.

With the designed platform, gaseous and liquid fuels can be tested individually under normal and extreme running conditions. In addition, the engine system exhaust can be connected to an existing emissions bench where gaseous and particulate exhausts will be measured and compared. Elements we designed include:

* liquid and gaseous fuel supply systems
* engine cooling system
* engine exhaust system
* instrumentation
* control system
* data acquisition system.

All of the above systems have been completed and installed, with the exception of the gaseous fuel system and the data acquisition system. Portions of the electrical control and monitoring system have been implemented, along with some analog instruments.

Overall capabilities of the testing platform are as follows:

1) Ability to test liquid and gaseous fuels:
   * alcohols
   * gasoline
   * diesel
   * Compressed Natural Gas (CNG)
   * Liquid Propane Gas (LPG)

2) Ability to run at variable speed ranging from 2000 rpm to stalling speed

3) Ability to apply variable load from free-running to 50 horsepower

4) Ability to connect to an emissions bench by utilizing an exhaust tap

5) Ability to perform an emergency shutdown.

In addition, this system will operate in accordance with ASTM Standards[1] for the following:

* engine oil pressure
* engine coolant temperature
* dynamometer water temperature and pressure
* engine speed
* engine exhaust temperature.

TABLE OF CONTENTS:

INTRODUCTION.. pg. 1
BACKGROUND AND PROBLEM STATEMENT.............................. pg. 2

PROJECT SUMMARY... pg. 3
PROJECT GOALS... pg. 4
SUMMARY OF PROJECT DELIVERABLES............................... pg. 8
PROJECT APPRAISAL... pg. 9

TECHNICAL MANUAL/DESCRIPTION OF DESIGN........................ pg. 10
PURPOSE OF MANUAL... pg. 11
ENGINE.. pg. 12
Engine Restoration.. pg. 12
Engine Liquid Fuel System..................................... pg. 13
Engine Gaseous Fuel System.................................... pg. 16
Engine Cooling System... pg. 18
Engine Exhaust System... pg. 21
Motor Starter... pg. 23
DYNAMOMETER... pg. 24
Dynamometer Restoration....................................... pg. 24
Dynomometer Cooling System.................................... pg. 26
Dynomometer Controlling System................................ pg. 28
CONTROLS.. pg. 31
Monitoring Controls... pg. 31
Program Description... pg. 33
DATA ACQUISITION.. pg. 35
System Data... pg. 35
Program Description... pg. 36
RECOMMENDATIONS FOR FUTURE WORK............................... pg. 37

USER MANUAL... pg. 38
START-UP PROCEDURES... pg. 39
SHUTDOWN PROCEDURES... pg. 41
Normal Shutdown... pg. 41
Emergency Shutdown.. pg. 41

LIST OF FIGURES:

Figure 1: Liquid Fuel Injection................................ pg. 13
Figure 2: Fuel Micrometer...................................... pg. 14
Figure 3: Gaseous Fuel Intake System........................... pg. 17
Figure 4: Engine Cooling -- Radiator Rotation.................. pg. 19
Figure 5: Engine Cooling System................................ pg. 20
Figure 6: Engine Exhaust System................................ pg. 22
Figure 7: Motor Circuit.. pg. 23
Figure 8: Power Diagram.. pg. 25
Figure 9: Dynamometer Cooling System........................... pg. 27
Figure 10: Dynamometer Controller.............................. pg. 29
Figure 11: PLC Inputs/Outputs.................................. pg. 32
Figure 12: PLC Wiring.. pg. 34

ENDNOTES.. pg. 42

LIST OF APPENDICES:

Appendix A: Energy Balance Equation.................... pg. 45
Appendix B: Expenditure Report........................ pg. 48
Appendix C: Project Contacts and Design Team Resumes.... pg. 50
Appendix D: Gaseous Fuel Injection Design Calculations.. pg. 58
Appendix E: PLC Program and Internal Registers.......... pg. 63
Appendix F: Process and Instrumentation Diagram......... pg. 69

The Solar Bullet
Solar Powered Race Vehicle Project
for the
Colorado School of Mines

From:
The Multidisciplinary Senior Design
Solar Powered Vehicle Research Team
Ken Anderson
Jim Ashmore
Robert DeHerrera
Steven Johnston
Andrew Muhlbach
Blaine Neptune

Design Management Team:
Dr. Ronald L. Miller
Dr. Barbara M. Olds
Dr. John U. Trefny

May 2, 1991

Executive Summary

In the interest of new technology, environmental concern, energy awareness, and national recognition, the Colorado School of Mines is designing and building a solar powered electric race vehicle. A team of six senior level students were chosen to manage the project and have been working toward the final design and construction of the solar vehicle. The students are educated in different disciplines, all of which contribute a unique part to the necessary design and implementation of the vehicle.

Many design considerations have been evaluated regarding the optimally efficient approach to building a solar powered vehicle. The project has been broken down into several areas: photovoltaic cells, batteries, motor/motor controller, materials, structure, aerodynamics, steering, suspension, and braking. Primary emphasis of design is focused on these areas, and each is key factor in the overall efficiency of the car.

Solar cells, batteries, and motor/motor controller constitute the major expense. Each component's efficiency must also be maximized in consideration of performance and cost. Single crystal silicon solar cells have been chosen due to their relatively high efficiencies at a fairly low cost. Silver/zinc batteries will be the optimal storage cells to use with the car. The vehicle will also utilize a high efficiency, permanent magnet, brushless DC electric motor. A suitable controller for this motor has also been selected. The chassis of the car will be an aluminum space frame consisting of thin-walled aluminum tubes connected at nodes by aluminum fasteners. Attached to the frame, body panels made of Kevlar-Nomex-Kevlar composite will form a teardrop shape, which has been determined to minimize aerodynamic drag. The "windshield" of the vehicle will be made of drape-molded polycarbonate tinted for driver comfort.

Under the management of the senior design team, three teams of sophomore students in the EPICS program were responsible for designing the steering, braking, and suspension systems. The steering system will be a simple rack and pinion assembly, the braking system will consist of disk brakes on the front wheels of the car, and the suspension system will be a single wishbone suspension used in conjunction with MacPherson-style struts on all four wheels.

The design will be constructed in several steps. The chassis, which has been the primary focus this year, will be the first component constructed, followed by the suspension, wheels, braking, and steering assemblies. From this point, the internal motor and batteries can be added resulting in a drivable vehicle. The next portion of the project will entail the implementation of body panels and solar array. This will be the final step in the production of the Solar Bullet and it will then be used in solar vehicle races representing the Colorado School of Mines.

The financing of the car will be supported by donations from local companies and interested parties. Several have shown interest in supporting the group either financially, through technical support, or through equipment donations. Continued work in this area will provide the necessary components to complete the

Solar Bullet.

The project will be an on-going project which will involve perhaps several years of effort by senior engineering students. Each year will entail specific design and implementation considerations. In the following years, each uncompleted design area will be implemented to the previous year's progress by the succeeding senior design team. In addition the design will be modified as needed to obtain a competitive solar race vehicle.

Table of Contents

Introduction..1

Chassis Design..2

Aluminum Fasteners..9

Materials Selection...13

Aerodynamics..14

Photovoltaics...18

Battery Selection...22

Motor/Motor Controller..24

Steering, Suspension, Braking, Tires, and Wheels................27

Project Administration..29

Project Facilities..30

Budget Plan...32

Funding...33

Evaluation..34

Bibliography..32

Appendix A - Computer Analysis

Appendix B - Autocad Drawings of Chassis

Appendix C - Hollaender Catalog

Appendix D - Aerodynamics

Appendix E - Solar Cell Data Sheet

Appendix F - Battery Selection

Appendix G - Motor/Controller System

Appendix H - Steering

Appendix I - Suspension

Table of Contents

Appendix J - Braking

Appendix K - Funding

Appendix L - Student Team Resumes

List of Figures

Figure 1: Node Fabrication....................................12
Figure 2: Estimated drag areas................................15
Figure 3: Priciple views of teardrop design...................18
Figure 4: Solar Cell I-V Curve................................22
Figure 5: Project hierarchy...................................31
Figure D-1: Configuration trade study.......................D-1
Figure D-2: Configuration trade results.....................D-2
Figure D-3: Skin Friction and transition analysis...........D-3
Figure F-1: Battery candidates..............................F-1
Figure F-2: Battery sizing..................................F-2
Figure G-1: Motor and controller data.......................G-1
Figure G-2: Motor and controller set........................G-2
Figure G-3: Vehicle power and control system circuit........G-3

List of Tables

Table 1: Chemical composition of fasteners....................10

Table 2: Fastener types...11

Table 3: Comparison of solar cell types......................19

Table 4: Budget...33

FINAL REPORT

SITE EVALUATION AT THE FORMER JEFFCO DIVISION I MAINTENANCE SITE

Submitted to:

Mr. Greg Sherman
Project Manager

Submitted by:
CSM Multidisciplinary Senior Design Team

Greg Dewey
Carol Duecker
Michelle Marshall
Gina Robledo
Doug Sigg

Dr. Cathy Skokan
CSM Team Manager

May 7, 1992

EXECUTIVE SUMMARY

The Jefferson County Public Works Department contracted Roy F. Weston, Inc. (WESTON) to find possible soil and ground water contamination on the Jeffco Division I Maintenance Site. An initial site characterization report was completed and contaminated soils were remediated.

Our project goals were:

1) to confirm that the site has no further contamination due to the petroleum storage and leaks and
2) to ensure that contaminant levels are appropriate for desired utilization of the site.

In order to meet our goal, we achieved the following objectives:

* use the Aquifer Simulation Model to predict flow direction and flow velocities of ground water
* use shallow geophysical techniques to determine the elevation of the water table and to find a culvert which controls the flow of Van Bibber Creek
* analyze soil samples previously taken by WESTON and sample two of the monitoring wells to ensure contaminants have not migrated since WESTON's initial site characterization.

Two ground water samples were taken and five soil samples were analyzed. We believe that the ground water and soil on the site appear to meet standards approved by the Environmental Protection Agency (EPA) and the Colorado Department of Health (CDH). The proposed use of the site as a park seems appropriate.

TABLE OF CONTENTS

1.0 Project Introduction 1

2.0 Site Assessment by WESTON 1

3.0 Purpose and Scope 2

4.0 Conclusions 3

5.0 Recommendations 3

6.0 Petroleum fuel behavior in the subsurface 5

7.0 Ground Water Model 8
- 7.1 Numerical Model 8
- 7.2 Ground Water Flow Model 10
- 7.3 Contaminant Transport Model 10
- 7.4 Transport Model Predictions 12
- 7.5 Analytical Model 14

8.0 Geophysical Methods 15
- 8.1 Water Table 15
- 8.2 Culvert Map 18

9.0 Ground Water Sampling 21
- 9.1 Sampling Technique 21
- 9.2 Chemical Analysis 21
- 9.3 Sample Results 22
- 9.4 Quality Assurance & Quality Control 23

10.0 Soils Investigation 24
- 10.1 Introduction 24
- 10.2 Field Work 24
- 10.3 Quality Assurance & Quality Control 26
- 10.4 Testing Results 26
- 10.6 Conclusions 29

REFERENCES 30

APPENDIX A: GROUND WATER MODEL RESULTS 31

APPENDIX B: SCHLUMBERGER DATA 34

APPENDIX C: GROUND WATER SAMPLE RESULTS 37

LIST OF FIGURES

Figure 1 -- Site of Former Jeffco Division I Maintenance Facility 4
Figure 2 -- Petroleum Behavior in the Subsurface 7
Figure 3 -- Location of Soil Vapor Tubes and Monitoring Wells 9
Figure 4 -- Model Ground Water Table and Flow Direction Output 13
Figure 5 -- Transport Model Output 13
Figure 6 -- Schlumberger Array 15
Figure 7 -- Locations of Schlumberger Array 17
Figure 8 -- Electromagnetic Methods for the EM-16 18
Figure 9 -- EM-16 Contour Map 20
Figure 10 -- Decision Tree Based on Type of Contaminant . . . 25
Figure 11 -- WESTON's In Situ Soil Vapor Data 27

LIST OF TABLES

Table 1 -- Solubility of Selected Hydrocarbons 6
Table 2 -- Estimated parameters for transport modeling . . . 11
Table 3 -- Flow velocity estimate (meters/year) 14
Table 4 -- Results of Monitoring Wells 5 and 6 22
Table 6 -- Results of Soil Analysis 28

Appendix D

Student Recruiting Flyer For MSD Program

MULTIDISCIPLINARY SENIOR DESIGN PROGRAM

Colorado School of Mines

Welcome to the multidisciplinary senior design program at the Colorado School of Mines. The purpose of this document is to briefly describe the program so that you may decide whether you wish to participate during your senior year. Increasingly, industry managers and engineers tell us they are concerned about the narrow technical confines in which senior design is currently taught -- more and more "real world" problems require engineers who are capable of working with people from other disciplines to achieve a satisfactory solution. Our two-semester (6 credit hour) course sequence addresses this concern by using **multidisciplinary** teams of students working with faculty from chemical engineering and petroleum refining, engineering (mechanical, electrical, civil), metallurgical engineering, engineering physics, geophysical engineering, geological engineering, mathematics, and liberal arts in cooperation with industry clients to solve complex, open-ended problems with both technical and non-technical constraints.

The course will meet for 1 lecture hour per week (tentatively scheduled for Thursday at 11 am) and 2 hours of group work (to be arranged). It is important to realize that this course sequence <u>will fully satisfy the senior design requirement in your department</u>. As with any senior design course, a significant portion of the work in this class will be performed by student groups outside of the formally scheduled class time. Each student group will be managed by one of the course faculty members, but will interact with all members of the faculty team during the year.

We will provide you with a learning experience that allows you to meet the following objectives:

- creatively solve open-ended, "real world" design problems
- apply a multidisciplinary approach to these problems, simulating industry experience
- work with other engineers, scientists, and liberal arts professionals in small project design teams
- appreciate and consider non-technical (ethical, social, cultural, aesthetic, political, etc.) constraints in your work
- develop meaningful client relations
- learn to conduct wide-ranging independent research as well as applying knowledge gained in previous courses
- enhance your oral and written technical communication skills

The following faculty members will be involved with the course next academic year:

Bill Copeland - MT	Cathy Skokan - GP
Nigel Middleton - EG	Ron Miller - CR
John Trefny - PH	Barbara Olds - LAIS

If you are interested in participating in this program, please fill out the attached form and return it to Dr. Miller or Dr. Olds as soon as possible. To simplify the record-keeping, each of you will enroll in a specially designated section of your own department's senior design course. Remember, this course will satisfy the senior design requirement in your department.

Some of the projects which we completed in past years are briefly described below. Similar projects are being arranged for next year's course.

Solar Electric Vehicle - Design, build, and test a prototype solar electric vehicle for competitions such as the GM Sunrayce. Prepare comprehensive design packages for photovoltaic modules, energy storage, chassis, motor and drivetrain, and aerodynamic body.

Optical Spinel Manufacture - Design, build, and operate a bench-scale apparatus to produce optically pure samples of transparent polycrystalline $MgAl_2O_4$ using the sol-gel alkoxide process developed at CSM. Prepare quantities of spinel samples sufficient for chemical and optical analysis.

Control System for Stationary Diesel Engine - Design and install control instrumentation, a new cooling system, and gas and liquid fuel supply systems for a CFR-type compression octane testing engine. Evaluate control system performance and fine-tune dynamic response to client specifications using standard gaseous and liquid fuels.

Automated Microcrystallizer - Design, build, and operate a computer-controlled bench-scale microcrystallizer apparatus to grow near perfect protein crystals using osmotic dewatering as the water removal technique. Evaluate system performance (nucleation and growth rates) using standard aqueous protein solutions.

Feed Mechanism for Corrugated Board Press - Prepare detailed engineering specifications for an automated feed mechanism to lift corrugated boards from a stack to the feed hopper of a board press. Simulate feeder control system and fine-tune dynamic response to client specifications.

Butane Splitter - Evaluate process alternatives for separating a mixed stream of isobutane and normal butane using traditional and vapor recompression distillation configurations. Optimize the design of each column configuration and estimate project costs for a 10 year project life.

Waste Site Remediation - Monitor subsurface contamination from leaking diesel oil and gasoline storage tanks at a specific site using geophysical techniques, soil sampling, and water sampling. Confirm that the site is suitable for use as a city park or recommend additional remediation actions.

Corrosion Demonstration - Design, build, and operate a series of small scale corrosion demonstration packages to introduce principles of corrosion and corrosion protection to engineers and technicians. Prepare and deliver a one-hour corrosion short course using the packages developed.

Colorado School of Mines
Multidisciplinary Senior Design Program

Request to Participate in the 1992-93 Design Course Sequence

I would like to participate in the two semester multidisciplinary senior design course sequence during the 1992-93 school year. I understand that I'm not guaranteed a seat in this course until notified by Drs. Miller and Olds, the course coordinators.

Name: ____

Option: ____

Local Address: ____

Local Phone: ________________________

Summer Address: ____

Summer Phone: ________________________

I would like to participate in the multidisciplinary senior design program for the following reasons:

Please return this form to Dr. Ronald L. Miller (CEPR Department) or Dr. Barbara Olds (EPICS Program) as soon as possible.

Appendix E

Student Perception Questionnaires and Summary of Survey Results

Colorado School of Mines
Multidisciplinary Senior Design Program

Perception Questionnaire #1

We are interested in your response to the following statements using the scale defined below:

|---------------|---------------|---------------|---------------|

1	2	3	4	5
strongly disagree	disagree	neutral	agree	strongly agree

Remember, there are no "right" or "wrong" answers in a survey like this one; just give us your honest opinion.

Course number: ____________________ Option: ________ GPA: _________

_____ 1. The engineering design method for solving problems differs from the scientific method for solving problems.

_____ 2. The engineering method for solving problems can be defined as: "the strategy for causing the best change in a poorly understood or uncertain situation within the available resources."

_____ 3. Engineering design can be defined as the activity of devising a system, component, or process to meet desired needs.

4. Each of the following activities is an important part of the design process:

_____ creativity

_____ open-ended problem solving

_____ design methodologies

_____ problem statements and specifications

_____ alternative solutions

_____ engineering analysis

_____ engineering synthesis

_____ feasibility studies

_____ detailed system descriptions

_____ economic analyses

5. Each of the following constraints must be considered during the design process:

_____ economic factors

_____ safety

_____ reliability

_____ aesthetics

_____ ethics

_____ social impact

_____ 6. Good oral and written communication skills are an essential attribute of a professional design engineer.

_____ 7. Multidisciplinary design teams (those in which team members possess expertise in two or more disciplines) are generally able to produce better engineering designs.

_____ 8. I have been exposed to engineering design methodologies in many of my classes at Mines. Classes where we've done design work include:

____ 9. Although creativity is an important part of engineering design, its not something that can be taught -- either you have it or you don't.

_____ 10. An engineering design team composed of several individuals can usually develop better designs than each of the team members could working alone.

<u>Comments</u>:

Colorado School of Mines
Multidisciplinary Senior Design Program

Perception Questionnaire #2

We are interested in your response to the following statements using the scale defined below:

|-----------------|----------------|----------------|----------------|

1	2	3	4	5
strongly disagree	disagree	neutral	agree	strongly agree

Remember, there are no "right" or "wrong" answers in a survey like this one; just give us your honest opinion.

Course number: ____________________ Option: _________ GPA: _________

_____ 1. The engineering design method for solving problems differs from the scientific method for solving problems.

_____ 2. The engineering method for solving problems can be defined as: "the strategy for causing the best change in a poorly understood or uncertain situation within the available resources."

_____ 3. Engineering design can be defined as the activity of devising a system, component, or process to meet desired needs.

4. Each of the following activities is an important part of the design process:

_____ creativity

_____ open-ended problem solving

_____ design methodologies

_____ problem statements and specifications

_____ alternative solutions

_____ engineering analysis

_____ engineering synthesis

_____ feasibility studies

_____ detailed system descriptions E-4

_____ economic analyses

5. Each of the following constraints must be considered during the design process:

_____ economic factors

_____ safety

_____ reliability

_____ aesthetics

_____ ethics

_____ social impact

_____ 6. Good oral and written communication skills are an essential attribute of a professional design engineer.

_____ 7. Multidisciplinary design teams (those in which team members possess expertise in two or more disciplines) are generally able to produce better engineering designs.

_____ 8. I have been exposed to engineering design methodologies in many of my classes at Mines. Classes where we've done design work include:

_____ 9. Although creativity is an important part of engineering design, its not something that can be taught -- either you have it or you don't.

_____ 10. An engineering design team composed of several individuals can usually develop better designs than each of the team members could working alone.

Comments:

Figure E-1
Multidisciplinary Design Teams Produce Better Designs

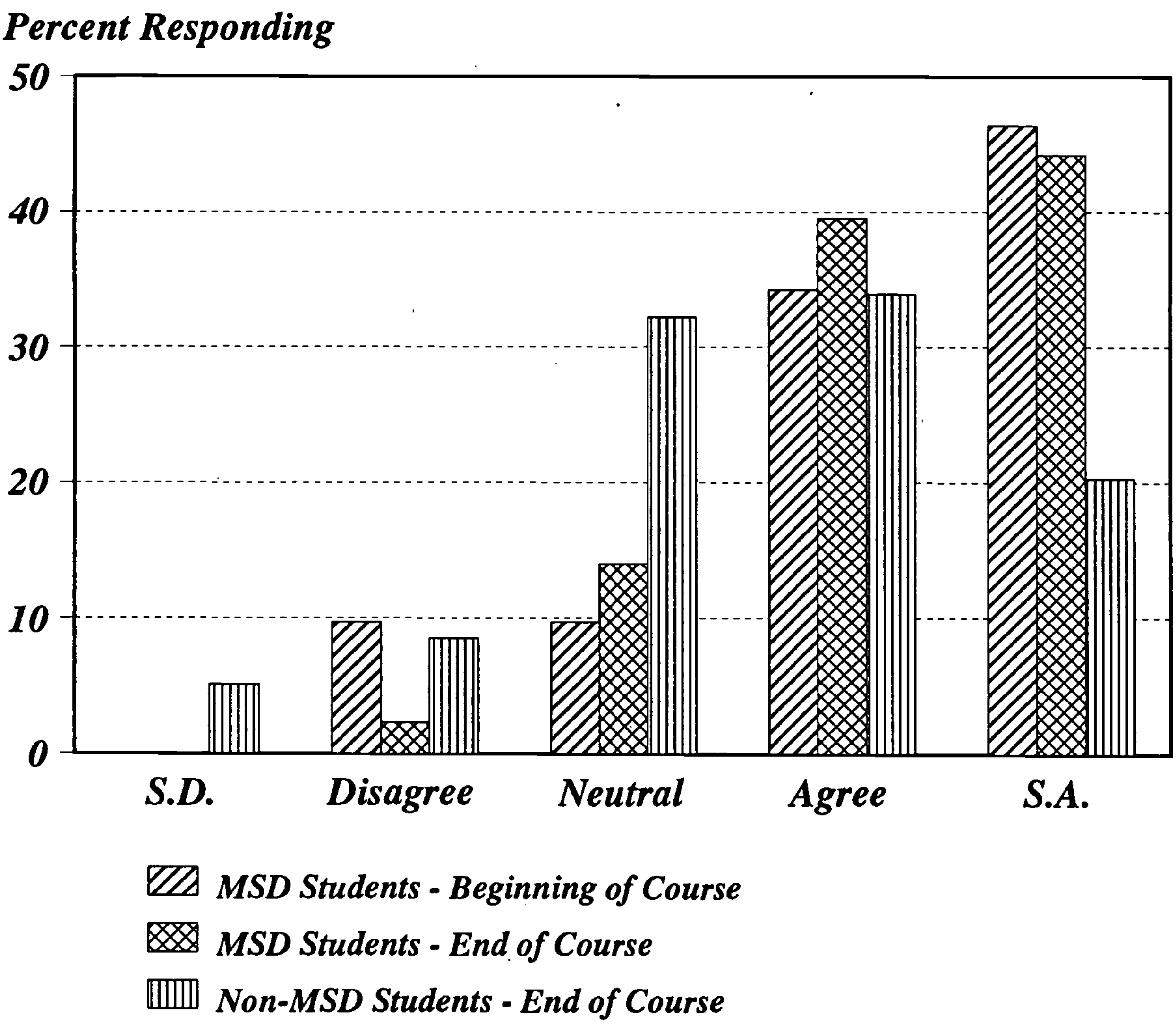


Figure E-2

Open-Ended Problem Solving Abilities are Important in Design Work

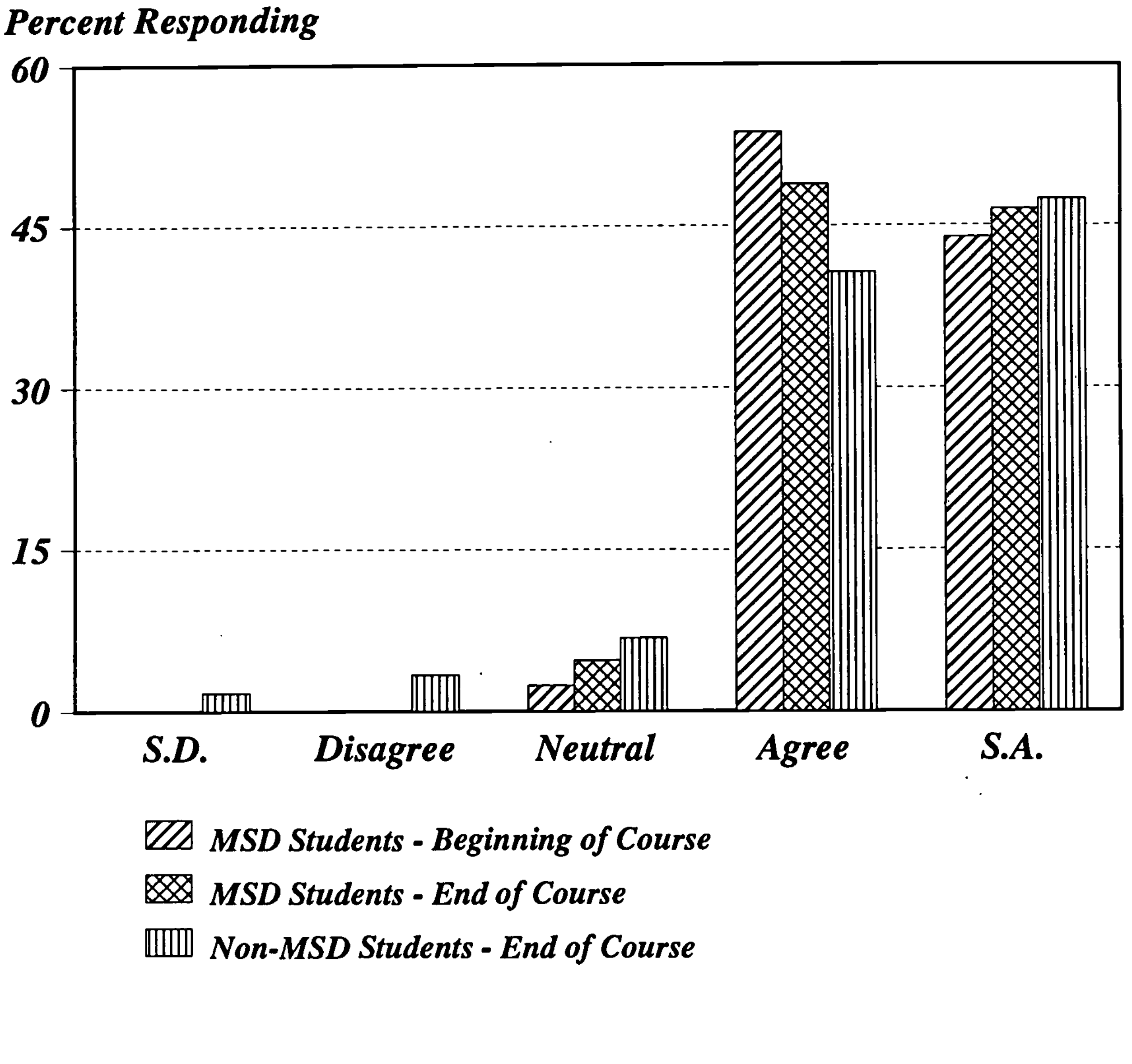


Figure E-3
Engineering Analysis is Important to the Design Process

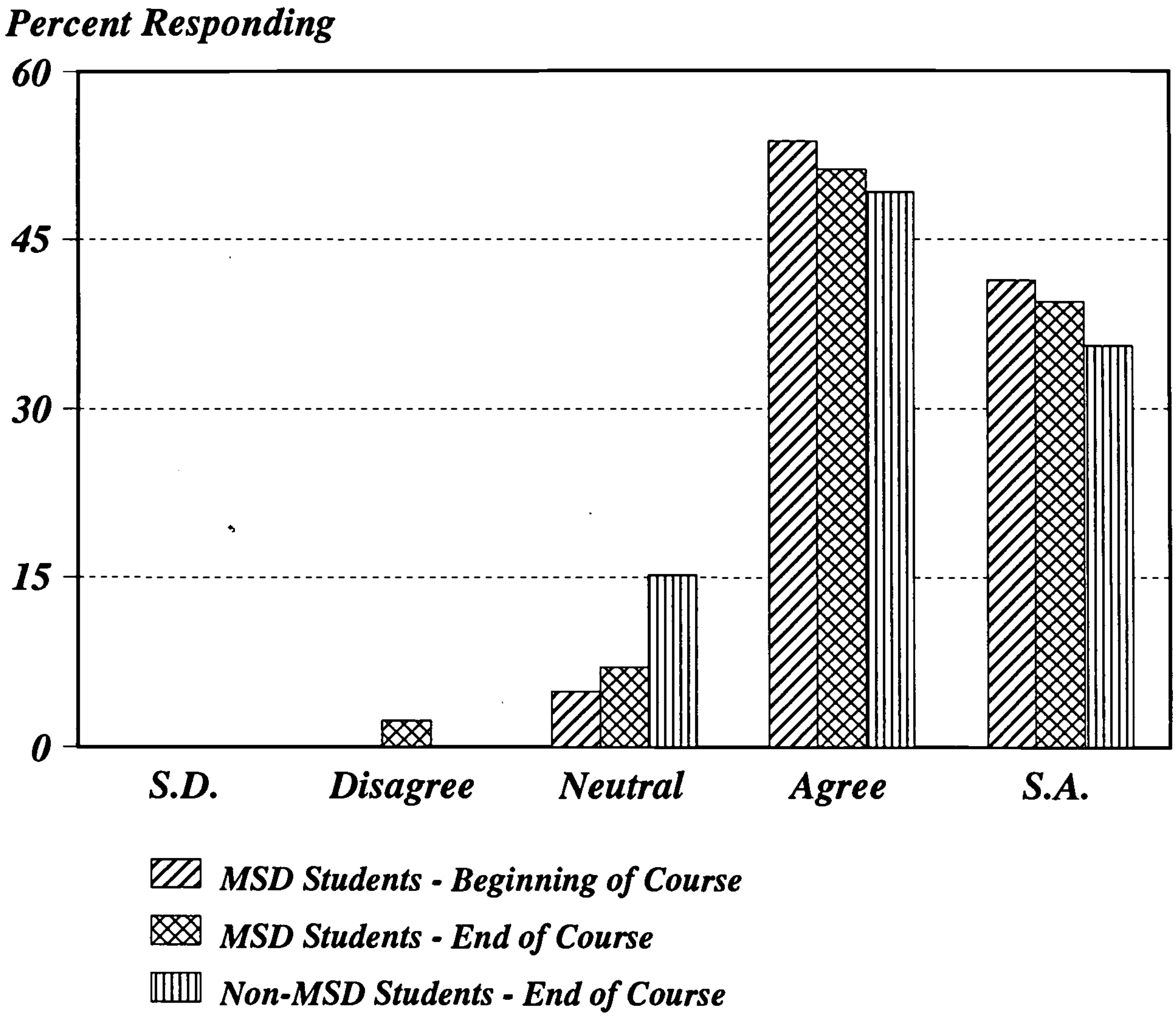


Figure E-4

Engineering Synthesis is Important to the Design Process

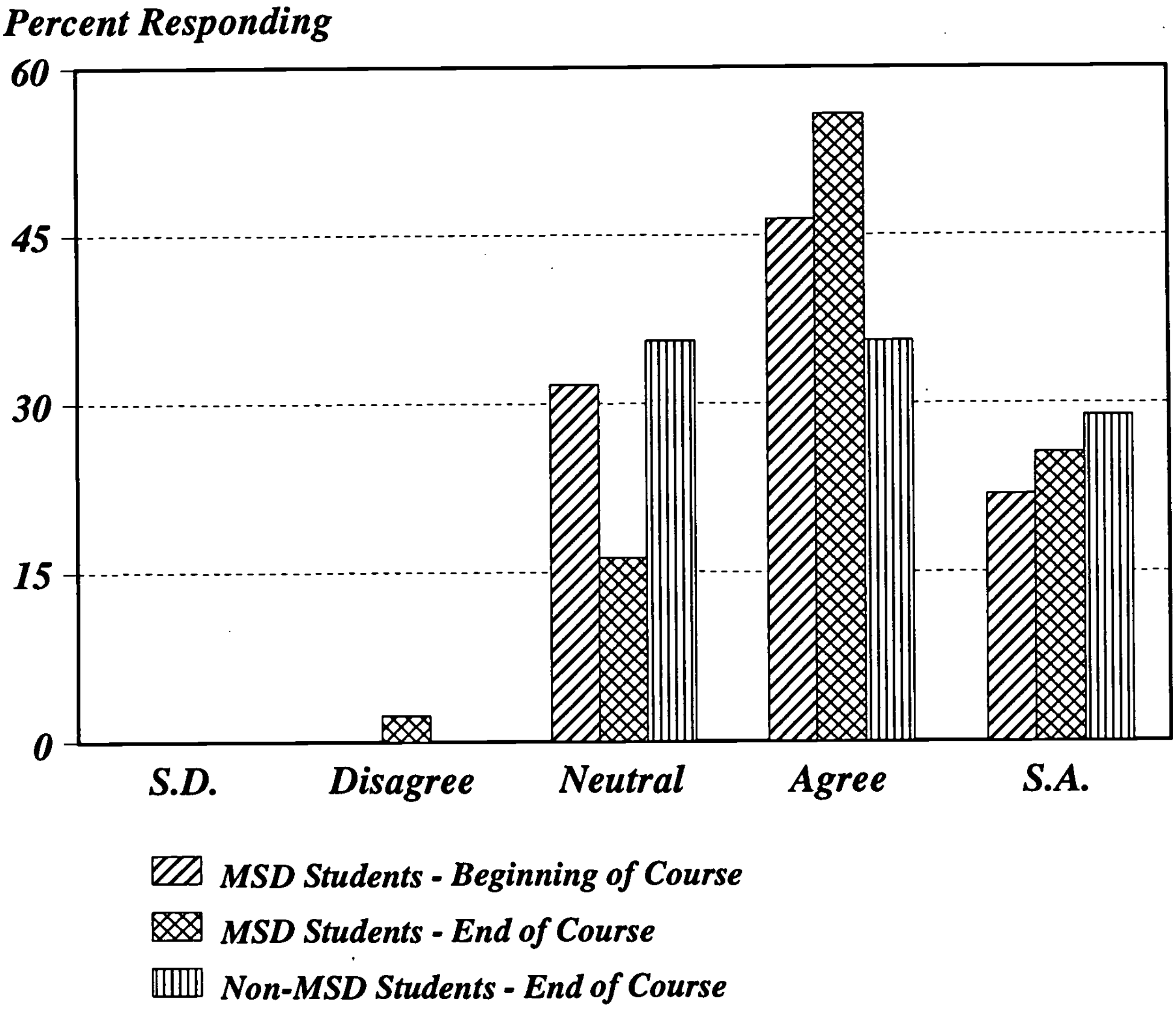


Figure E-5

Engineering Design Methods Differ from the Scientific Method

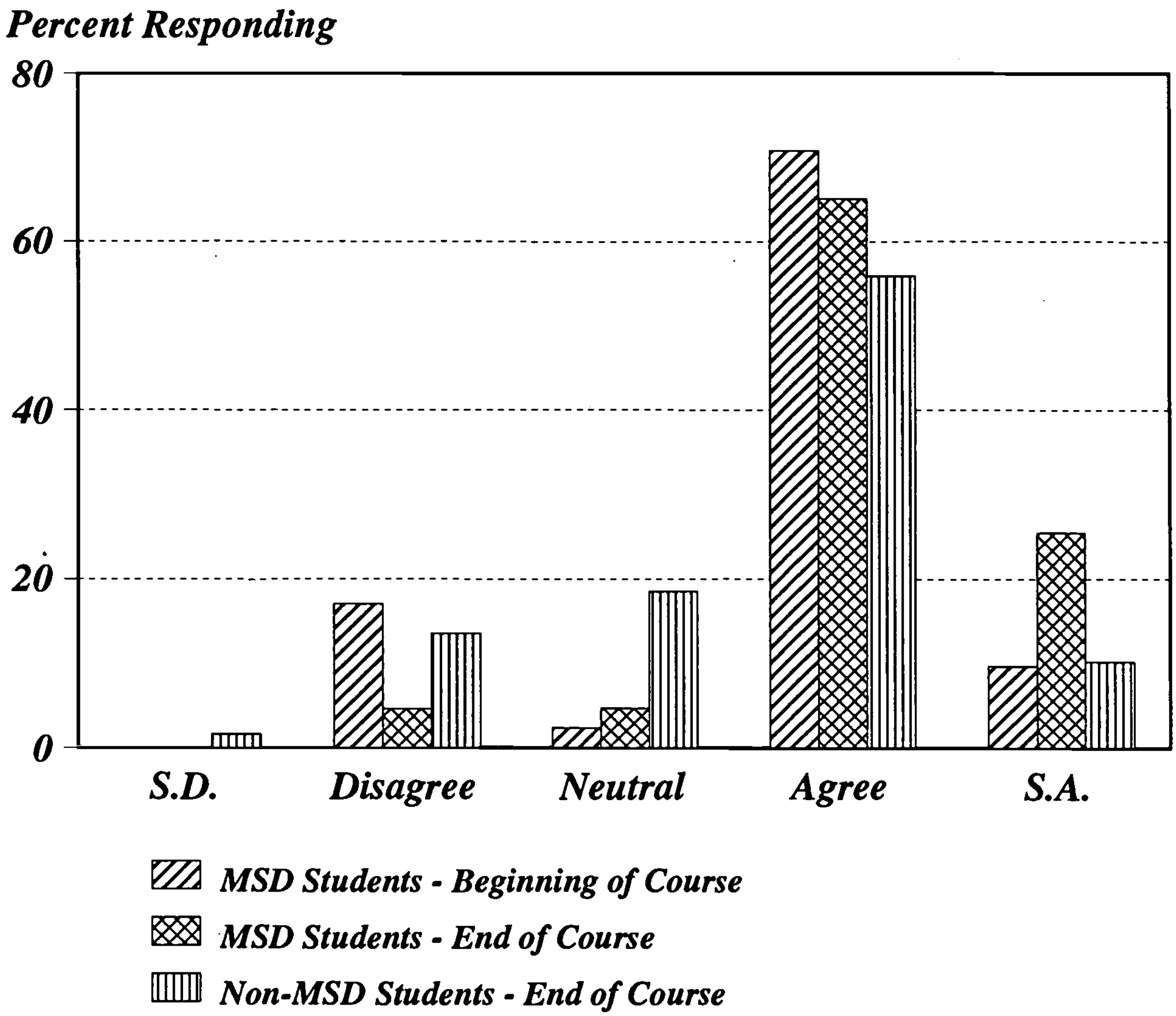


Figure E-6
Engineering Design Devises Systems or Processes to Meet Desired Needs

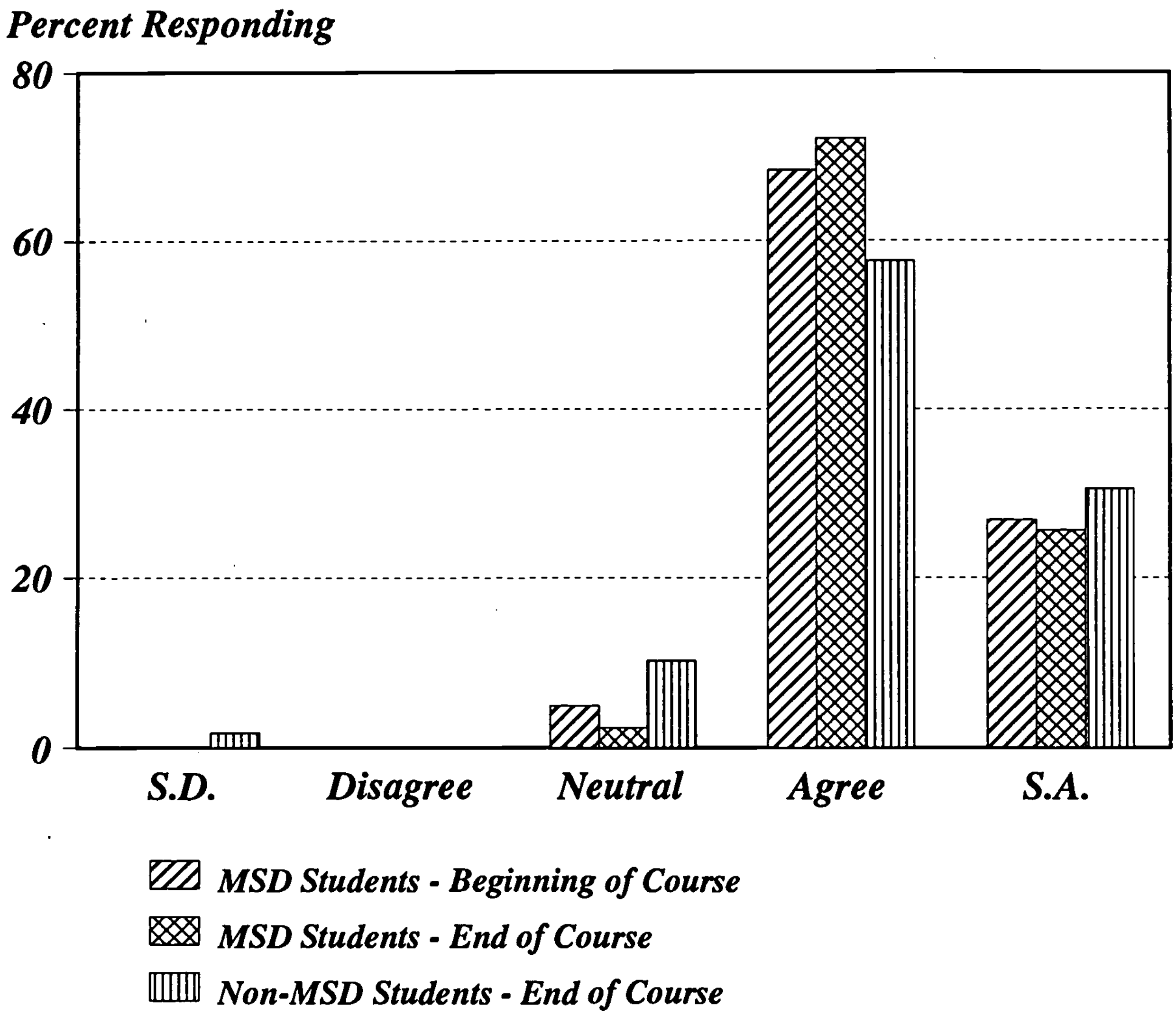


Figure E-7

Design Engineers Must Possess Good Communication Skills

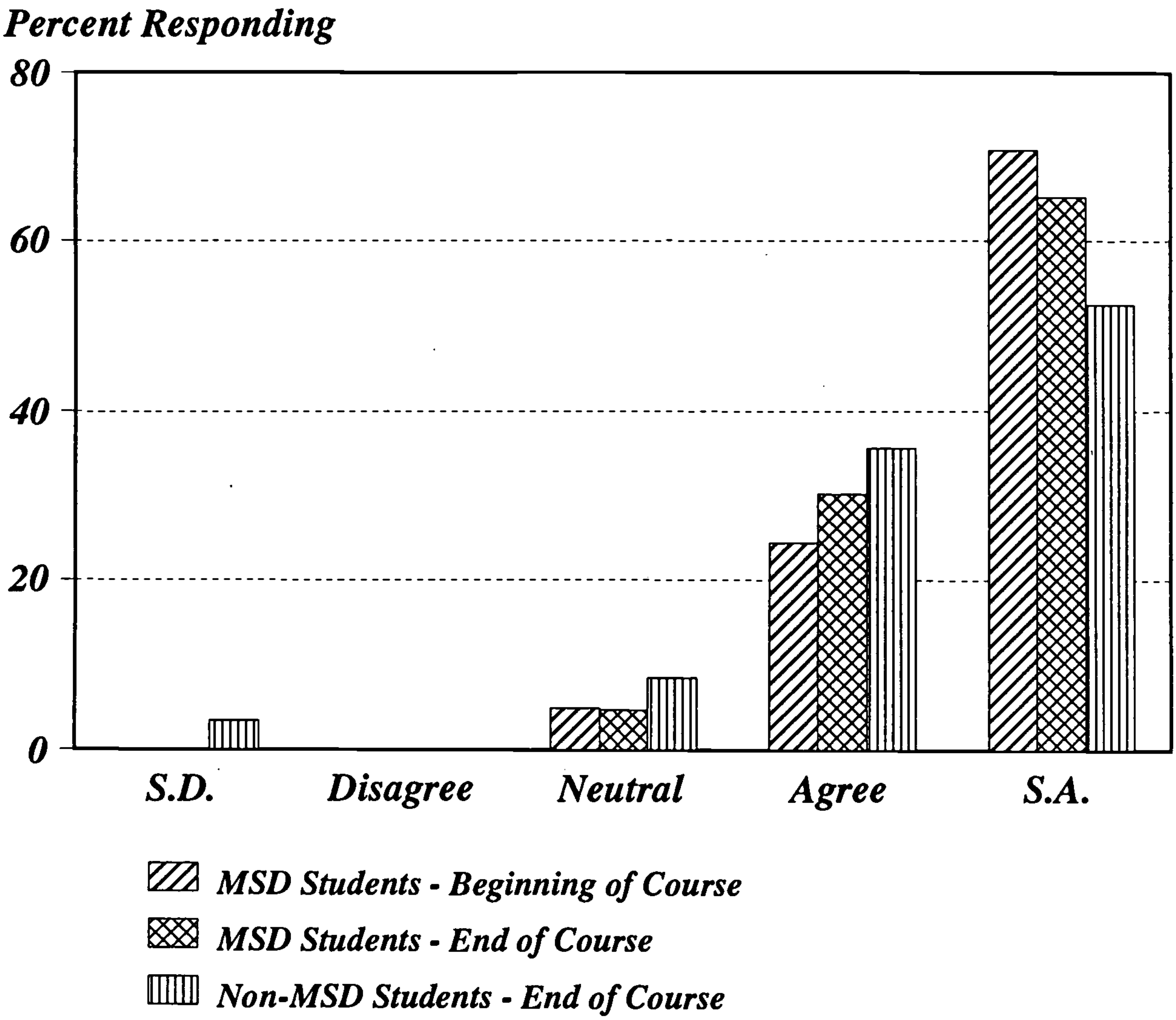


Figure E-8

Ethical Considerations are an Important Part of the Design Process

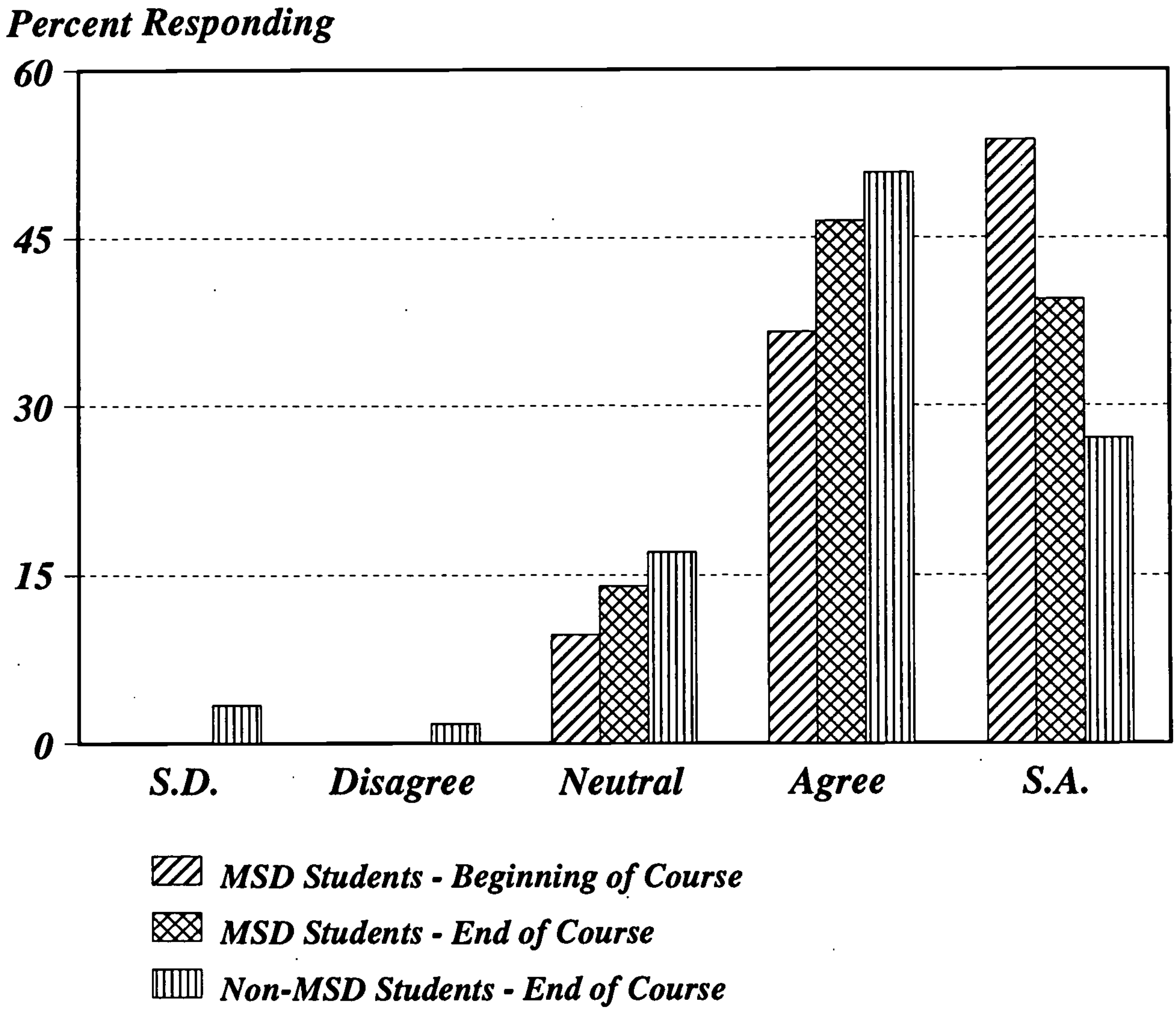
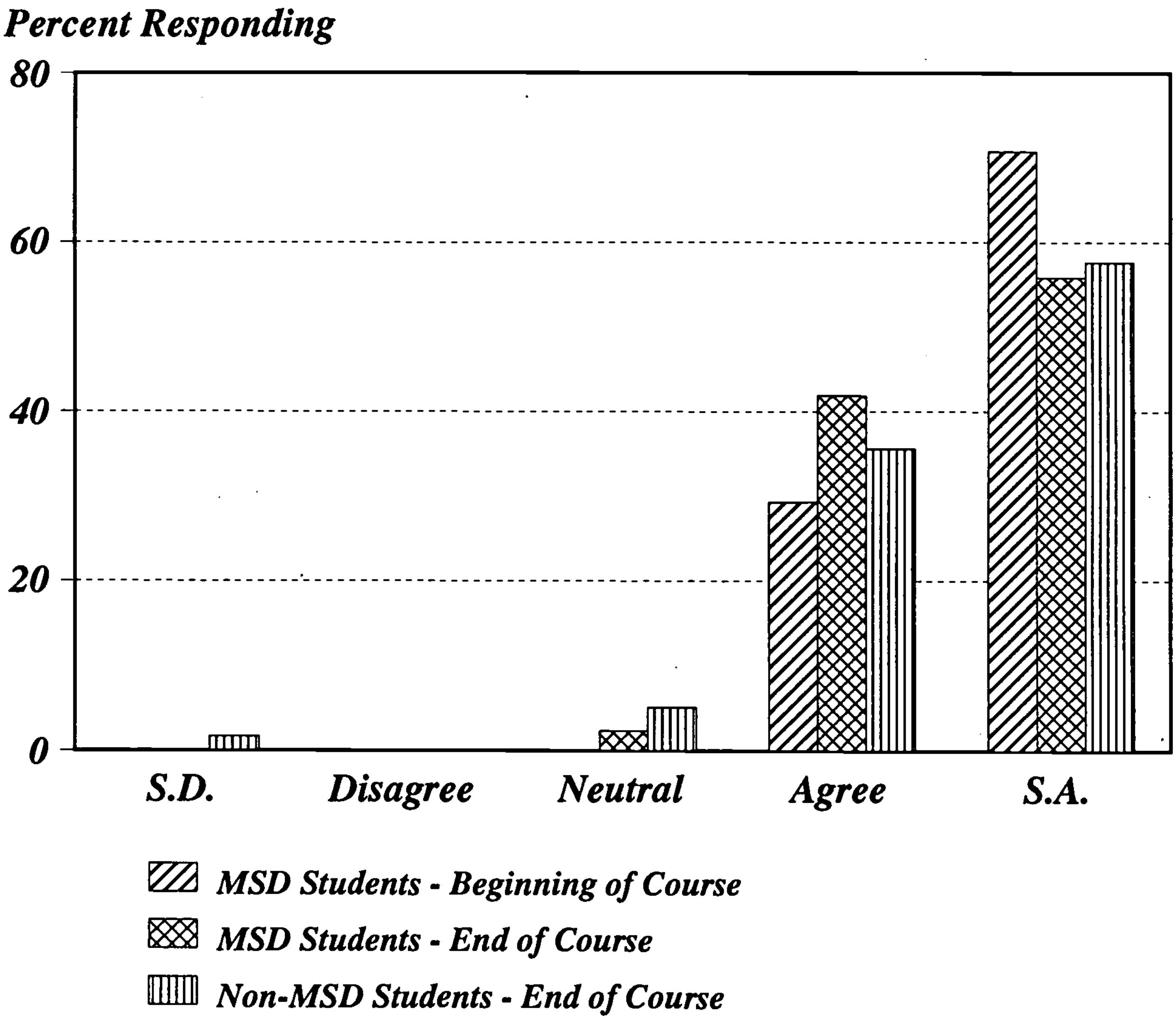


Figure E-9

Safety is an Important Design Consideration



Appendix F

Course, Peer, and Self Evaluation Questionnaires and Summary of Survey Results

Colorado School of Mines
Multidisciplinary Senior Design Program

Course and Design Management Team Evaluation Form
Spring Semester, 1991

As we near the end of the spring semester, we would like some evaluative feedback about your perceptions of the course. Please give us your candid response to each of the items listed below and provide us with any other comments you would like us to see. We will not see the completed forms until after grades are submitted at the end of the semester, so please provide us with an honest and fair evaluation. Please use the following scale for numerical ratings:

1 - extremely poor   2 - poor   3 - average
4 - good   5 - excellent

1. Satisfaction with the course content and organization: __________
   Comments:

2. Satisfaction with technical work: __________
   Comments:

3. Satisfaction with written communications work: __________
   Comments:

4. Satisfaction with oral communications work: __________
   Comments:

5. Satisfaction with client relations: __________
   Comments:

6. Satisfaction with the following course topics:

engineering ethics and whistleblowing: _________
liability and safety: _________
sexual harassment and affirmative action: _________
patent disclosure: _________

7. What do you think is the most valuable part of this course? Why?

8. What do you think is the least valuable part of this course? Why?

Please use the numerical scale shown earlier to rate the course instructors, Drs. Olds and Miller, and your faculty project manager. Do not provide a rating for any other faculty members listed. Use the space below to give us any additional comments you'd like us to see.

Dr. Olds: _______ Dr. Miller: _______ Dr. Middleton: _______

Dr. Trefny: _______ Dr. Copeland: _______ Dr. Knecht: _______

Comments:

Colorado School of Mines
Multidisciplinary Senior Design Program

Course and Design Management Team Evaluation Form
Spring Semester, 1992

As we near the end of the spring semester, we would like some evaluative feedback about your perceptions of the course. Please give us your candid response to each of the items listed below and provide us with any other comments you would like us to see. We will not see the completed forms until after grades are submitted at the end of the semester, so please provide us with an honest and fair evaluation. Please use the following scale for numerical ratings:

1 - extremely poor	2 - poor	3 - average
4 - good	5 - excellent	

1. Satisfaction with the course content and organization: __________
   Comments:

2. Satisfaction with technical work: __________
   Comments:

3. Satisfaction with written communications work: __________
   Comments:

4. Satisfaction with oral communications work: __________
   Comments:

5. Satisfaction with client relations: __________
   Comments:

6. Satisfaction with the following course topics and speakers:

engineering ethics and whistleblowing: __________
liability and safety: __________
sexual harassment and affirmative action: __________
patent disclosure: __________

Phil Doe: __________
Bob McPhearson: __________
Ed Crabtree: __________

7. What do you think is the most valuable part of this course? Why?

8. What do you think is the least valuable part of this course? Why?

Please use the numerical scale shown earlier to rate the program directors, Drs. Olds and Miller, and your faculty project manager. Do not provide a rating for any other faculty members listed. Use the space below to give us specific feedback for your project manager.

Dr. Olds: ________ Dr. Miller: ________ Dr. Middleton: ________

Dr. Trefny: ________ Dr. Copeland: ________ Dr. Skokan: ________

Project Manager strong points:

Project Manager weak points:

General comments:

Colorado School of Mines
Multidisciplinary Senior Design Program

Peer Evaluation Form
Fall Semester, 1990

In many professional settings, your performance will likely be evaluated by both your peers and your supervisors. Such an evaluation system is valid for this course as well, since you are primarily responsible to your design teammates for completing any design tasks you are assigned. Please give us a candid evaluation of each of your design team members (excluding yourself) by filling in the table below. Use a scale of 0 (extremely poor) to 10 (excellent) for your evaluation. This information will be held in strict confidence and will only be seen by faculty members in the Design Management Team.

Your name: ____________________ Design team: ____________________

	Design Team Members				
	__________	__________	__________	__________	__________
Category					
Reliability	____	____	____	____	____
Attitude	____	____	____	____	____
Technical ability	____	____	____	____	____
Leadership	____	____	____	____	____
Cooperation	____	____	____	____	____
Inventiveness	____	____	____	____	____
Overall rating	____	____	____	____	____

Comments:

Colorado School of Mines
Multidisciplinary Senior Design Program

Peer Evaluation Form
Spring Semester, 1991

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Your name: ____________________ Design team: ____________________

Design Team Members

Category	________	________	________	________	________
Reliability	___	___	___	___	___
Attitude	___	___	___	___	___
Technical ability	___	___	___	___	___
Leadership	___	___	___	___	___
Cooperation	___	___	___	___	___
Inventiveness	___	___	___	___	___
Overall rating	___	___	___	___	___

Comments:

Colorado School of Mines
Multidisciplinary Senior Design Program

Peer Evaluation Form
Fall Semester, 1991

In many professional settings, your performance will likely be evaluated by both your peers and your supervisors. Such an evaluation system is valid for this course as well, since you are primarily responsible to your design teammates for completing any design tasks you are assigned. Please give us a candid evaluation of each of your design team members (excluding yourself) by filling in the table below. Use a scale of 0 (extremely poor) to 10 (excellent) for your evaluation. This information will be held in strict confidence and will only be seen by faculty members in the Design Management Team.

Your name: ____________________ Design team: ____________________

Design Team Members

Category	________	________	________	________	________
Reliability	___	___	___	___	___
Attitude	___	___	___	___	___
Technical ability	___	___	___	___	___
Leadership	___	___	___	___	___
Cooperation	___	___	___	___	___
Inventiveness	___	___	___	___	___
Overall rating	___	___	___	___	___

Comments:

Colorado School of Mines
Multidisciplinary Senior Design Program

Peer Evaluation Form
Spring Semester, 1992

In many professional settings, your performance will likely be evaluated by both your peers and your supervisors. Such an evaluation system is valid for this course as well, since you are primarily responsible to your design teammates for completing any design tasks you are assigned. Please give us a candid evaluation of each of your design team members (excluding yourself) by filling in the table below. Use a scale of 0 (extremely poor) to 10 (excellent) for your evaluation. This information will be held in strict confidence and will only be seen by faculty members in the Design Management Team.

Your name: ______________________ Design team: ______________

Design Team Members

Category	________	________	________	________	________
Reliability	___	___	___	___	___
Attitude	___	___	___	___	___
Technical ability	___	___	___	___	___
Leadership	___	___	___	___	___
Cooperation	___	___	___	___	___
Inventiveness	___	___	___	___	___
Overall rating	___	___	___	___	___

Comments:

Colorado School of Mines
Multidisciplinary Senior Design Program

Self Evaluation Form
Spring Semester, 1991

Name: ______________________________

We would like your perceptions about how valuable this two-semester design sequence has been to you and what you feel you have learned. Please provide responses to the questions listed below.

1.) List your four or five most important individual contributions to your team's work this year. Tell us how your expertise enabled you to help your team succeed on your project.

2.) Give us your overall impression of the two semester sequence. What did you like about working in a multidisciplinary team? What did you dislike? What was easy to do? What was difficult? What did you learn? Do you think all the work you did was worth it? What suggestions can you give us for next year's class?

Colorado School of Mines
Multidisciplinary Senior Design Program

Self Evaluation Form
Spring Semester, 1992

Name: ____

We would like your perceptions about how valuable this two-semester design sequence has been to you and what you feel you have learned. Please provide responses to the questions listed below.

1.) List your four or five most important individual contributions to your team's work this year. Tell us how your expertise enabled you to help your team succeed on your project.

2.) Give us your overall impression of the two semester sequence. What did you like about working in a multidisciplinary team? What did you dislike? What was easy to do? What was difficult? What did you learn? Do you think all the work you did was worth it? What suggestions can you give us for next year's class?

Figure F-1
Student Satisfaction with Course Content and Organization

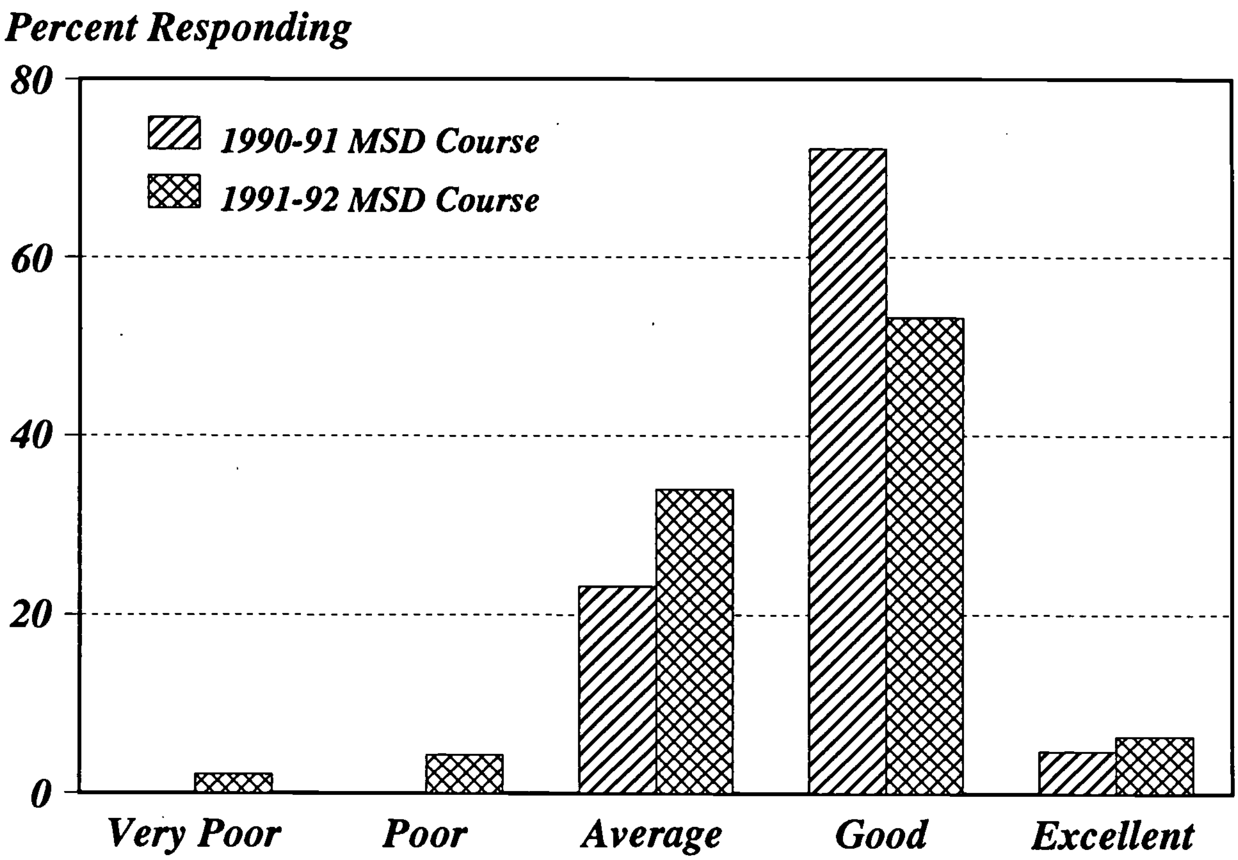


Figure F-2
Student Satisfaction with Technical Work

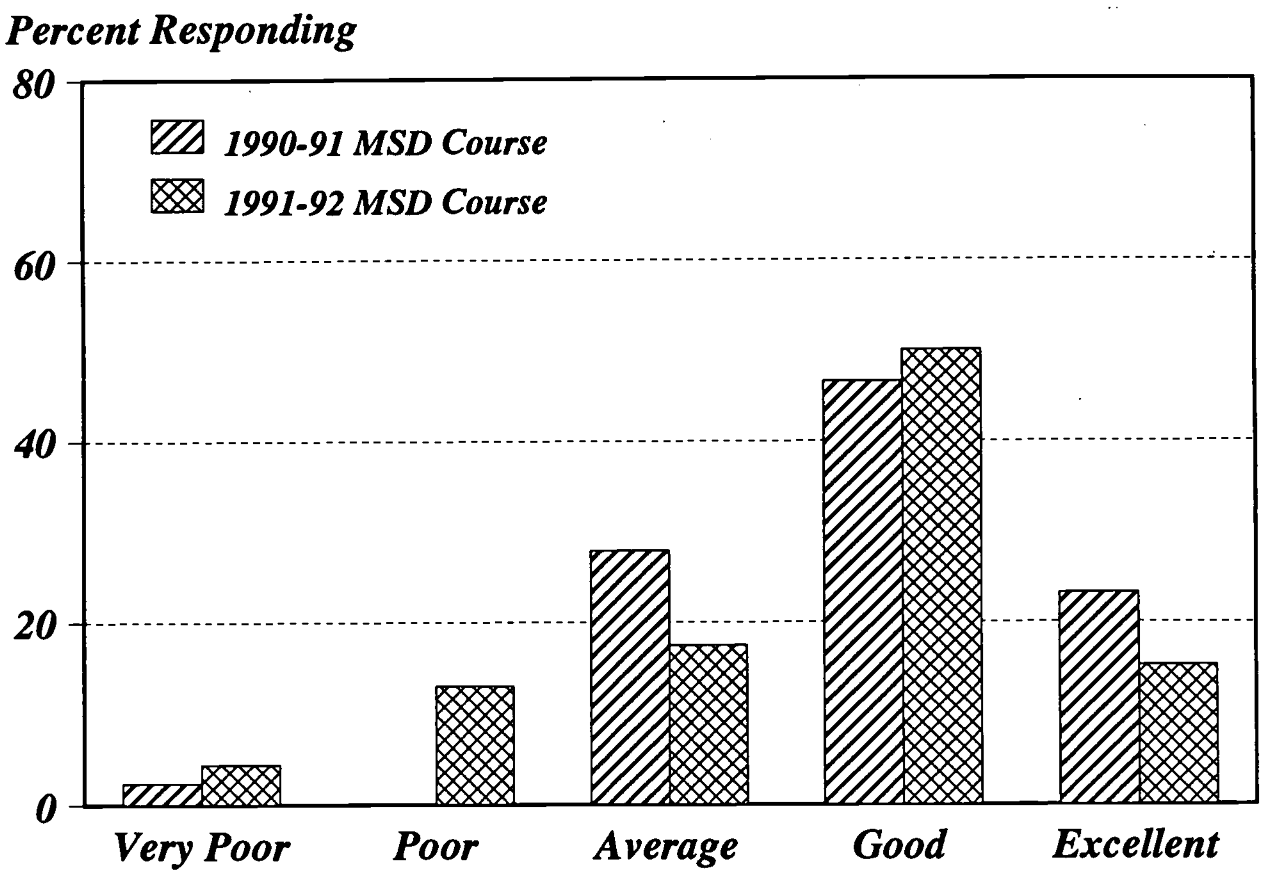


Figure F-3

Student Satisfaction with Written Communication Work

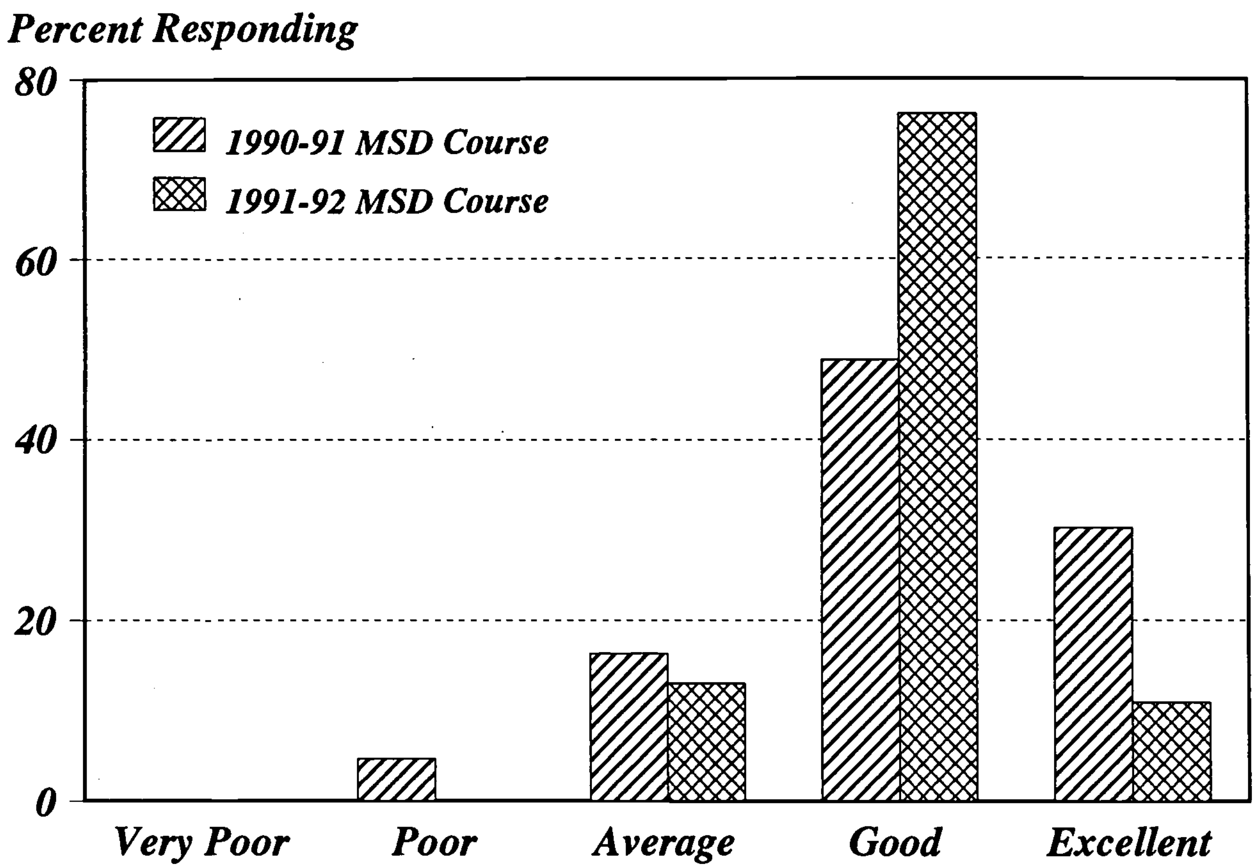


Figure F-4
Student Satisfaction with Oral Communication Work

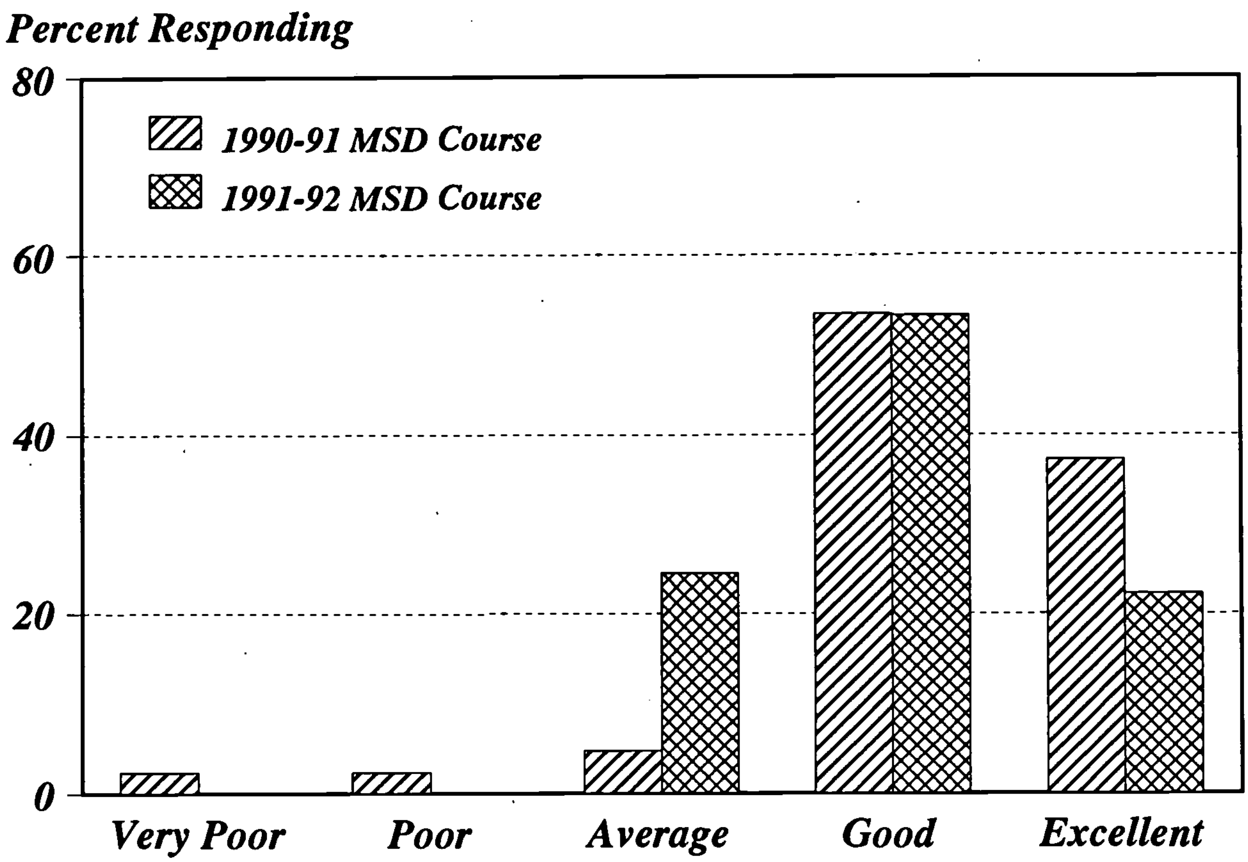


Figure F-5

Student Satisfaction with Selected Design Topics: 1990-91 Course

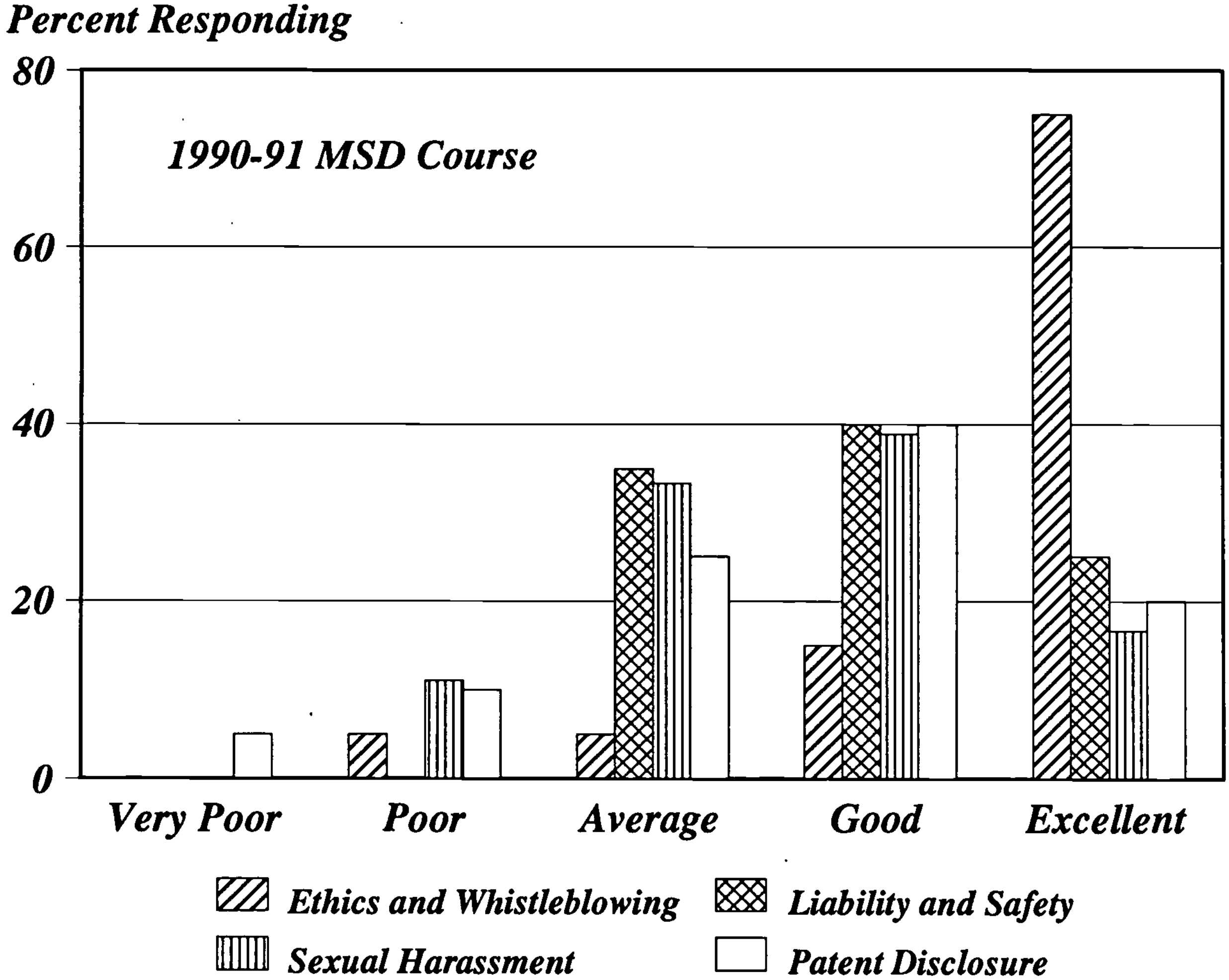
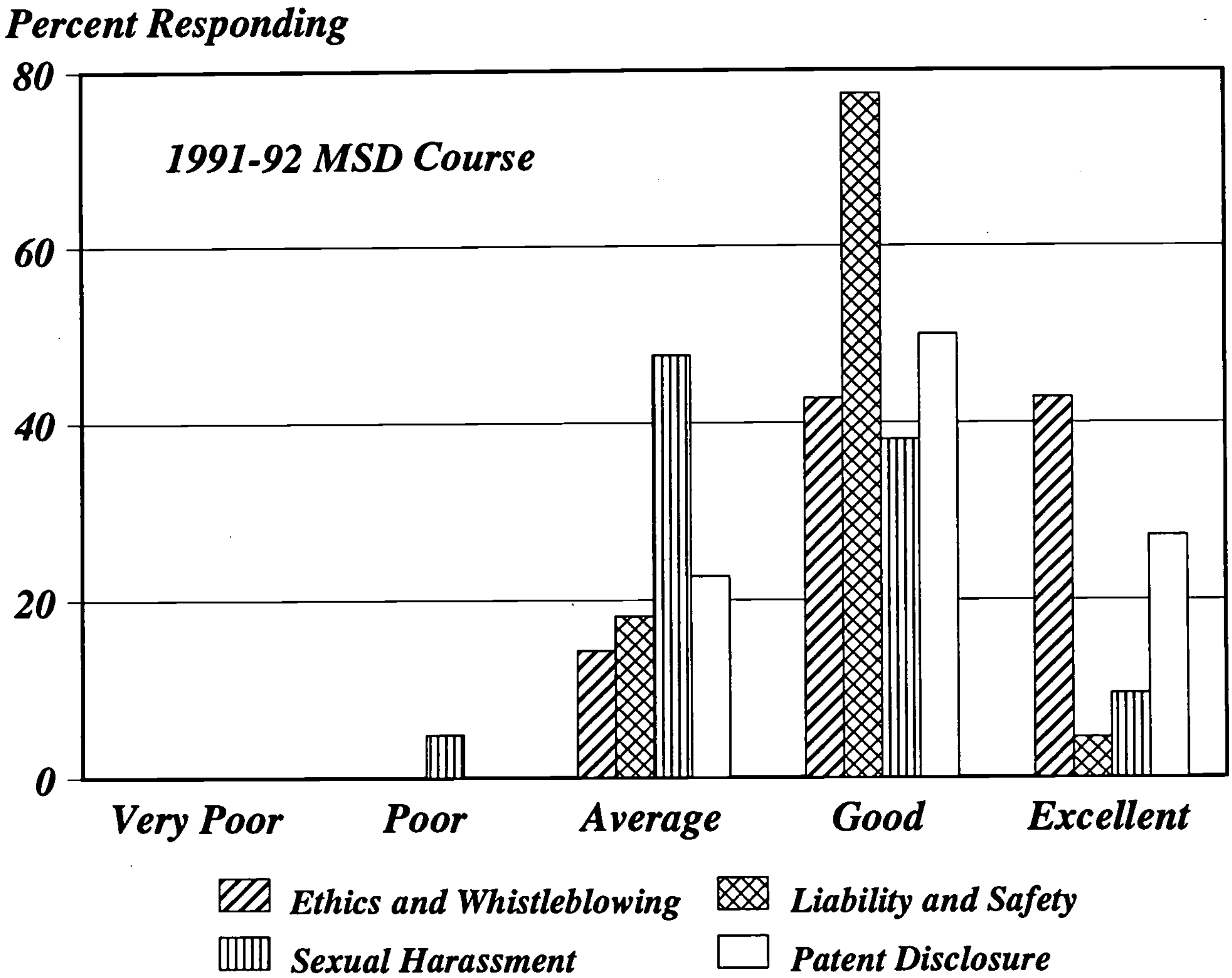


Figure F-6

Student Satisfaction with Selected Design Topics: 1991-92 Course



Selected Student Comments from Self Evaluation Forms

"The multidisciplinary approach gave a real-world feel to the design program. As experts in different areas, individuals were able to contribute to a complete project."

"We generated a better design than we would have individually or within our own department thanks to our varied technical and personal backgrounds. I learned a great deal about group dynamics and well as all of the technical stuff.

"I found this class very rewarding. I particularly liked the multidisciplinary structure because it allows for innovative approaches to problem-solving. I think the work we did this semester was worth the time spent."

"I really liked this class - working with a multidisciplinary team was great -- there was always someone who knew how to solve whatever problem we encountered. It was very valuable finding a common language we could all understand."

"I liked working with students from other departments who had taken other classes than I had. I learned to work better in a group and I feel all the work was worth it."

"Overall I found that participating in a multidisciplinary design course was a very beneficial and valuable experience. I felt the proposal preparation and public final presentation were especially beneficial."

"Liked working in these groups because I forget how to work with people from other majors. It was good to work with other people and have to explain things to them that seem routine to me and vice versa. I am worried that I may have missed out on something in my regular senior design course, but I don't know for sure."

"I very much liked working with a multidisciplinary team. It was informative to be working with other disciplines on our project. I learned to respect what other disciplines do and I learned the value of multidisciplinary teams."

"I feel that I learned a lot more in this class than in the typical engineering design courses. One thing that I did not like was that it seemed one semester wasn't enough time everything we planned to do."

"I liked getting a new perspective on how those in different disciplines work. Meeting the demands and needs of all group members was difficult at times."

"I liked working with people from different options."

"Overall, this course was beneficial. I learned to express technical ideas in a way that could be understood by persons of different disciplines."

Appendix G

Client Evaluation Form and Summary of Survey Results

Colorado School of Mines

Multidisciplinary Senior Design Program

Client Evaluation Form

Client: ______________________________

Project: ______________________________

Year Completed: ______________________________

We are interested in your <u>candid</u> responses to the following questions concerning your experiences with the multidisciplinary senior design program at CSM. Use the scale shown below to answer questions 1-8. Thank you for providing this information; we use your feedback to help improve the senior design experience of our students.

1	2	3	4	5
poor	below average	average	above average	excellent

_____ 1. Overall, what was the technical quality of the students' proposed solution?

_____ 2. How well did the students understand the problem and respond to your solution requirements?

_____ 3. How would you assess the students' problem-solving abilities?

_____ 4. Evaluate the students' ability to consider all problem constraints (including non-technical ones) in solving the problem.

_____ 5. How well did the students research the problem?

_____ 6. Rate the quality of the final written report.

_____ 7. Rate the quality of the final oral presentation.

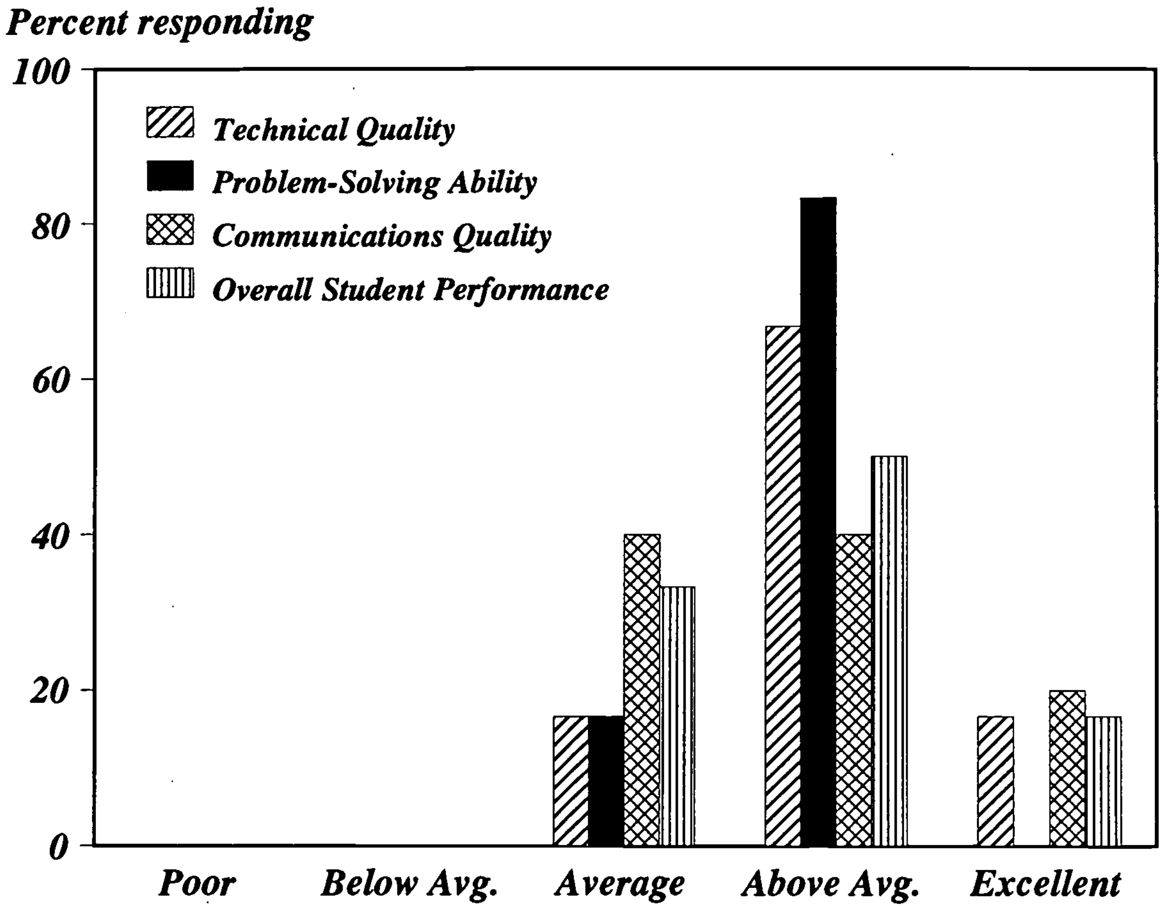
_____ 8. Overall, how would you rate your senior design experience this year?

9. In what way, if any, will you use the students' design in your work?

Y N 10. Would you work with us again on a future project?

Please provide any other comments you would like us to see on the back of this evaluation form. Thank you for your time and interest in our senior design program.

Summary of Client Evaluations of Student Design Team Performance



Appendix H

Articles Publicizing the MSD Program Published in Mines Magazine

Microcrystallizers and solar powered cars

Mines Seniors Complete Research Designs

BY ELLEN GLOVER

For the last academic year about 25 seniors from CSM participated in a new capstone design class. The group represented four different departments which collaborated with local companies and government organizations to solve real engineering design problems (see *Mines Magazine*, October 1990).

In the new course, students from the different engineering departments worked together as a design team on one of four projects:

- designing and installing computerized test equipment on an engine at the Colorado Institute for Fuels and High Altitude Engine Research (CIFER) located on campus
- working with Alpha Optical Systems, Inc. (a subsidiary of Coors Ceramics Company) to develop a very hard, erosion-resistant, and chemically stable optical material used in advanced weapons and aerospace optical systems
- developing an automated microcrystallizer for the National Institute of Science and Technology (National Bureau of Standards) in Boulder
- designing and building a solar electric car for the Solar Energy Research Institute located in Golden which will eventually compete in national races.

Students were guided by a design management team consisting of the program directors, Drs. Ron Miller of the Chemical Engineering Department and Barbara Olds of the Humanities Department and Drs. John Trefny of Physics, Nigel Middleton of Engineering, Robert Knecht of Chemical Engineering, and Bill Copeland and Gerry Martins of Metallurgical and Materials Engineering.

At a reception in May just before graduation, the seniors and their clients met with the faculty to present their findings. Most of the projects will continue next year as a new class continues the research begun last fall. A description of each project has been included for your information.

Design of an automated microcrystallizer

The National Institute of Standards and Technology asked students on this project to design, build and operate a computer-controlled bench-scale microcrystallizer apparatus to grow near perfect protein crystals for use in genetic engineering and pharmaceutical development. The process used a newly developed technique called osomotic dewatering to slowly remove water from a protein solution and control crystal growth. The number of crystals grown and the size of each crystal was monitored by measuring laser light scattering in the protein solution. A personal computer was used to control the rate of crystal nucleation and growth during crystallization experiments which lasted up to two weeks.

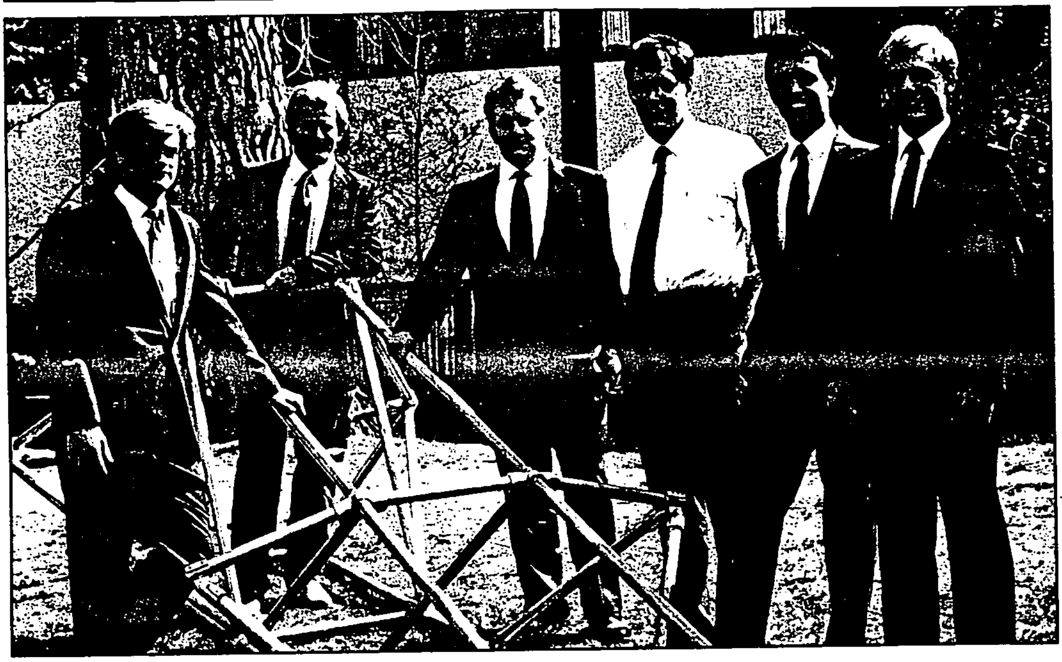
Standing with faculty advisor Nigel Middleton, (far left) are students associated with the CIFER project: left to right, Martin Supitar, Holly Sprackling, Don Cameron and Don Wojciechowski.

Design of control system for a stationary diesel engine

The Colorado Institute for Fuels and High Altitude Engine Research acquired a CFR-type compression octane testing enused for the production of optical elements. These optical elements have special transmittance properties, combined with exceptional hardness and strength, as well as unique chemical and thermal properties.

The work was based on graduate work performed at the CSM Metallurgy Department: the students' design was predominantly based on the gas phase hydrolysis approach developed by Karen Phillips, a master's degree student, with the aid of Dr. Gerry Martins, the team's technical advisor within the department.

The seniors found the process they used can produce a spinel powder with precise control and very high purity. Their group recommends continued efforts with this method of powder production; their conclusion was this high purity, custom-designed spinel powder would theoretically allow Alpha Optical Systems to produce larger and more perfect optical lenses.



Solar car designers were Ken Anderson, Blaine Neptune, Andrew Muhlbach, Jim Ashmore, Robert DeHerrera, and Steve Johnston.

gine fitted with an eddy current dynamometer. The objective of this project was to install new instruments, controls, a cooling system, and fuel supply system so that the engine can be used to test gasoline and diesel fuels.

CIFER staff were available as technical consultants to the student design team completing this project.

It should be noted that the engine the students received was in critical condition. It had been in storage for more than ten years, and no one knew if it would run. The design team had to restore the fuel induction, cooling, and exhaust systems, electrical monitoring and controls. The dynamometer has also been restored; the restoration and modifications were completed by CIFER's lab technician under the supervision of the design team.

Manufacturing optical spinels using the sol-gel process

One team designed, modified, and operated an existing bench scale process to manufacture quantities of spinel powder sufficient for evaluating its chemical and optical properties. The client has been Alpha Optical Systems, Inc. (a subsidiary of Coors Ceramics Company) and the contact person was Dr. Don Roy, who is vice president for new product development.

Spinel powder is an advanced polycrystalline ceramic which is

The Solar Bullet

While some of the projects may be hard to visualize, the "Solar Bullet," Mines' entry to the world of solar-electric cars, is easier to imagine especially since the students were able to build a prototype frame of the car in the last few weeks of the spring semester.

Those associated with the spinel powder research were: John Dworak, Dr. Don Roy (client), Julianne Horton, Debbie Marks-Carvill, Mike Fryer, Jodi Davidson, and Dina Svaldi.

Penny Iwamasa, Jeff Ranney, Dorena Barnes, Scott Thornburg, and Danny Frederick developed an automated microcrystallizer with NIST in Boulder.

The objective of this project has been to design, build and test a solar powered vehicle. With the long-term goal of actually building a full-scale, competitive machine, the project is viewed as a major undertaking which will require several generations of senior design students. A comprehensive design will include the photovoltaic modules, electrical energy storage, a lightweight chassis and engine, an aerodynamic body design, and many other specialized components.

Students hope to enter national or international competitions such as the GM SUNRAYCE USA or the American Tour de Sol. Financial support of the car will be supported by donations from local companies and interested parties. Several have shown interest in supporting the group either financially, through technical support, or through equipment donations.

Now that this program has tangible results to show both students and faculty there is more interest on campus according to Dr. Miller. Last fall the program attracted about 50 students initially, but the class was limited to 25 to keep it to a manageable size. Miller forsees more students enrolling in the capstone program as word of the projects spreads.

Next year, studies for geophysical engineering, geological engineering and possibly chemistry will be added to the program to work projects related to subsurface remediation of hazardous wastes.

DESIGN WITH A PURPOSE

STUDENTS CAP OFF A CAREER

by Ellen Glover

At the start of this fall's semester about 25 seniors from CSM gathered in a classroom to begin a new capstone design class. Unlike other senior level classes where everyone in class is from the same discipline, these students had to introduce themselves to one another—they are from four different departments that are participating in projects with local companies and government organizations to solve real engineering design problems.

The students represent a new multidisciplinary approach to teaching engineering design which will build on the skills they gained through the innovative freshman and sophomore course sequence entitled EPICS (Engineering Practices Introductory Course Sequence).

EPICS combines open-ended problem solving work with instruction and practice in technical oral and written communication, graphics, and computing. After they complete EPICS, students take what have traditionally been standard junior- and senior-level design courses taught in their degree department, but there is some concern on campus that students have not been exposed to the same type of "realism" in their upper division courses, especially in the capstone design sequence.

Dr. Ron Miller of the Chemical Engineering Department, one of the faculty involved in the design sequence, says the course is an option, but is not for everyone. "About 50 students were turned away from the class; our group includes about 25 students from chemical engineering; civil, electrical and mechanical engineering; metallurgical and materials engineering; and physics. We have solicited four very interesting projects which have a cross-disciplinary focus. It's artificial to have a project solved by professionals only in one discipline; in industry you're more likely to have several types of engineers, perhaps an economist and a chemist working on a problem so we felt the senior design sequence should reflect this. Not everyone is best served by a very narrow education, especially when industry is seeking multi-talented people," he said.

Dr. Ron Miller

Miller and Dr. Barbara Olds of the Humanities Department recently sought and received funding from the Department of Education's FIPSE (Fund for the Improvement of Post-Secondary Education) program to fund the capstone program.

In the new course, students from the different engineering departments will work together as a design team on one of four projects:

- designing and installing computerized test equipment on an engine at the Colorado Institute for Fuels and High Altitude Engine Research (CIFER) located on campus
- working with Coors Ceramics Company to develop a very hard, erosion resistant, and chemically stable optical material used in advanced weapons and aerospace optical systems
- developing an automated microcrystallizer with the National Institute of Science and Technology (National Bureau of Standards) in Boulder
- designing and building a solar electric car with the Solar Energy Research Institute located in Golden which will eventually compete in national races.

Students will be guided by a design management team consisting of the program directors, Miller and Olds and one faculty member from each department. Drs. John Trefny of Physics, Nigel Middleton of Engineering, Robert Knecht of Chemical Engineering, and Bill Copeland and Gerry Martins of Metallugical and Materials Engineering join Miller and Olds in teaching the course.

Client benefits are numerous

The clients involved in the capstone course—SERI, CIFER, Coors Ceramics and the National Institute of Science and Technology stand to gain from this program. On the practical side, they will receive a great deal of productive work from some very bright students. Though Drs.

Olds and Miller will not guarantee workable solutions, they can, based on their EPICS experience, promise whole-hearted effort and refreshingly creative strategies.

The clients will also benefit from their interactions with both faculty and students. The faculty contacts may lead to collaborative research and certainly should increase mutual understanding and promote discussion between industry and academe. Students view the course as an opportunity to experiment with what they have learned, and to meet prospective employers.

Training versus educating

"Throughout our design experience at CSM, we are striving not just to train but to educate our students by having them practice the kinds of integrative, creative thinking they will need to solve the increasingly complex problems they will face as practicing engineers in the 21st century," Dr. Olds said.

With the established EPICS program and the new senior design sequence, Mines will have a curricular structure that includes some aspect of client-based engineering design throughout the undergraduate curricula.

"We feel our students will graduate with a quality engineering design experience that will help them to understand and appreciate the issues involved in solving complex problems and provide them with the ability to approach such problems with confidence and creativity," concluded Dr. Olds.

If at the end of the year the design sequence proves successful it may be expanded to include geotechnical and exploration projects, involving students from the Geology, Geophysics, Mining and Petroleum Engineering Departments.

Homecoming

OCTOBER 19, 1990

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