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PLANETARY MATERIALS AND RESOURCE UTILIZATION: AN INTERDISCIPLINARY ENGINEERING DESIGN COURSE AT MICHIGAN TECHNOLOGICAL UNIVERSITY

W. I. Rose[1], J. B. Paces[1], C. A. Chesner[1]
B. J. Pletka[2], A. Hellawell[2], S. K. Kawatra[2], and J. E. Pilling[2]
[1]Department of Geological Engineering, Geology, and Geophysics
[2]Department of Metallurgical and Materials Engineering
Michigan Technological University
Houghton, MI 49931

ABSTRACT

A new course was developed and instituted in the spring quarter of 1989 dealing with topics related to space resource utilization and related engineering. The course development required a concerted, coordinated effort, because a similar course which might be used as a guide could not be identified anywhere and the interdisciplinary perspective that was required was not concentrated anywhere on our university campus. A dominant role in the course was played by 13 visiting speakers from NASA, USGS, private companies and universities who each gave 2 or 3 lectures. Ten faculty in six different departments provided introductory and connective lectures in the course. Students in the class worked on interdisciplinary design projects which culminated in papers and oral presentations. Each of the six design groups consisted of several engineers with different disciplinary roots. The entire course lecture sequence, about 50 hours in all, was videotaped. We have edited this resource for distribution to others interested in this topic area. In this paper, we will discuss our experiences in developing the course, including the course syllabus and speaker list.

INTRODUCTION

The original motivation for the course was to introduce faculty, graduate students, undergraduates and our own community to the possibilities and engineering challenges involved with lunar bases and space manufacturing. We perceived that President Bush's recent statements about the future of planetary exploration would, if implemented, foster interesting career opportunities for engineers, and as one of the country's largest engineering schools, we felt that these opportunities should be emphasized. As an additional motivation, many of the faculty with space-related interests saw the course as a means to develop interdisciplinary engineering efforts with colleagues who had similar research interests. After attending an April 1988 NASA Symposium on Lunar Bases and Space Activities in the 21st Century, we decided that the interdisciplinary scope required to effectively solve lunar base and space manufacturing/engineering problems was not currently being realized in our engineering curricula.

INITIAL EFFORTS

It was decided that a new course was necessary to address space related engineering problems, but it was not clear what form was appropriate and what content should be included. Existing courses in several different departments contained some relevant material. However, an appropriate combination of these existing courses was never assembled because an established degree program focusing on space engineering problems was not available. Several factors led us to develop a single interdisciplinary course that would allow us to stimulate students and faculty to become involved with a new interdisciplinary curriculum. No individual faculty member at Michigan Tech had the breadth to organize a course dealing with a variety of space engineering topics. We also felt that after developing a single course, we would have a better appreciation of what individual topics could best be expanded into separate courses. Finally, the effort required to develop a sequence of courses would have placed a tremendous burden on even a core group of interested faculty.

Our activities resulted in a course for engineering students which gave them sufficient background on extraterrestrial materials and processing conditions so that specific design problems could be examined. The course had a strong orientation toward planetary materials utilization since the core group of faculty had backgrounds in materials science, mineral processing, and geology. We decided that the new course should be accessible to advanced undergraduates, who had basic engineering and science backgrounds, and to graduate students at different levels who would provide more academic maturity to the student population. We also hoped that a broad group of faculty would participate in the course.

We were unsuccessful in identifying appropriate courses on other campuses that could serve as a useful guide. Courses dealing with lunar and planetary geology exist on many campuses but focus on purely scientific topics. Engineering courses were available dealing with topics such as microgravity and materials given by Jean Koster at the University of Colorado that were rather specialized. What we wanted was a course that emphasized a strong interdisciplinary engineering design element related to space resource utilization.

Several procedural problems with regard to the "mechanics" of the class also arose. It was not clear, because of our desire for an interdisciplinary format, what department the course should reside in. We were concerned that if an upper division course was assigned to a particular department, students in other departments would be reluctant to take it. University procedures for courses not specifically assigned to an academic department were very cloudy and we were unsure how students would react to becoming involved in such courses. This presented us with an important issue faced by university faculty interested in interdisciplinary research and educational topics and who want to involve students in an upper division class outside of their normal curriculum. Our solution was to use "wild-card numbers" for classes designated as "Advanced Topics" in various departments.

We realized that visiting speakers could play a crucial role in the course given the limited number of internal faculty with space-related experience. It was also felt that external speakers could stimulate further research projects by interacting with faculty and graduate students. We had difficulty devising a comprehensive list since each of the core group of faculty had ideas for appropriate external scientists and engineers. It also became clear that we needed financial resources to support the travel of the external speakers and an individual to organize the course; the latter was necessary since it would be difficult for any single faculty member to have enough time to devote to all the details of the course organization.

We convinced university administrators to provide funds on the basis that such a course would help initiate a creative new engineering program at Michigan Tech which did not seem to be available at other universities. In addition, it was argued that the course would help foster a greater interaction between university faculty and various external groups already examining such problems. Since we planned to videotape the lectures of the outside speakers, we also pointed out that the course would benefit the university by having these lectures available as an up-linked, televideo course and as a non-profit educational package. The budget was divided into three major categories: video-production costs, travel expenses for the external speakers and support for a course coordinator. Jim Paces was selected as the coordinator since he was a recent Ph.D. graduate from the Geology program at Michigan Tech and had been a NASA Graduate Student Trainee at Johnson Space Center. The latter gave him a number of contacts we used in developing our external speakers list.

ORGANIZATIONAL DETAILS PRIOR TO THE CLASS

The initial task of the course coordinator was to organize a course outline (Table 1) and to develop a list of external speakers (Table 2). At first, the course syllabus changed constantly. Although we were interested in a very broad focus, it became obvious that we should concentrate on topics that the internal faculty had expertise in. As a result, the course content focused on self-sufficiency in future space operations by examining in-situ resource utilization and microgravity processing of materials. Topics covered in the course could be placed, therefore, into three broad categories: non-terrestrial geological resources (lunar mineralogy, petrology, surface conditions, remote sensing), utilization of non-terrestrial resources (geotechnical and mining, lunar power systems, lunar materials processing systems), and utilization of non-terrestrial conditions (low gravity and high vacuum materials processing in space).

We were fortunate to have the help of Dr. Wendell Mendell of NASA-JSC in developing the external speaker list. After examining an early copy of the course outline, Dr. Mendell provided a list of potential speakers in each of the topic areas we had selected. Most of the "targeted" outside speakers accepted our invitation and their stimulating lectures were an integral part of the success of our course. Each speaker usually gave two different talks: a more-technically oriented lecture for the class participants, and a more-generalized presentation open to the public. The involvement of Dr. Mendell and other NASA personnel greatly contributed to this portion of the course.

Another responsibility of the coordinator was to build interest in the new course within the faculty and students of Michigan Tech. This was important because internal faculty could summarize fundamentals, introduce the concepts discussed by external speakers, and bridge any gaps between presentations by

Table 1

Planetary Materials and Resource Utilization
Spring Term 1989
Syllabus

Speaker	Topic
Week 1	
W. I. Rose, GE	Organization, Introduction and Purpose
Paul Spudis	Geological History of the Moon
Paul Spudis	Exploring the Moon in the 21st Century
Paul Spudis	A Lunar Base in the Crater Mare Smythii
Week 2	
John Alred	Engineering a Lunar Outpost
John Alred	NASA Office of Exploration Future Studies
J. B. Paces, GE	Lunar "Ore" Deposits: Mineralogy
S. T. Bagley, BIO	Biological Extraction Processes
Week 3	
W. I. Rose, GE	Magmatic Processes and Rock Types
W. W. Predebon, ME	Surface Processes: Impacting
S. K. Kawatra, MY	Surface Processes: Radiation
Larry Taylor	Lunar Mineralogy and Petrology
Larry Taylor	Origin and Evolution of the Lunar Soil
Larry Taylor	Thin Sections of Lunar Samples: A Demonstration of Mineralogy and Petrology of Rocks and Soils
Week 4	
J. Zimbelman	Mars as a Planet
J. Zimbelman	Exploration of Mars: Past, Present and Future
W. I. Rose, GE	Remote Sensing - Polar Orbiter Mission
Lab Session	Lunar Thin Section/Remote Sensing Lab
Week 5	
B. D. Alkire, CE	Geotechnical Engineering
David Carrier	The Strength of Lunar Soil
David Carrier	Mining on the Moon
Ron Sovie	Power Systems Options for Lunar/Space Base Applications
Ron Sovie	Power Systems for Production, Construction, Life Support and Operations in Space
Week 6	
Dave McKay	Processing Raw Materials
Dave McKay	Emerging Technology for Utilization of Lunar Resources
S. K. Kawatra, MY	Concentration/Separation
B. J. Pletka, MY	Ceramics Engineering
Week 7	
James Blacic	Properties, Production and Application of Lunar Glasses
James Blacic	Melt Tunneling: An Example of Unique Lunar Engineering Applications
J. E. Pilling, MY	Cellular Structures

<u>Week 8</u>	
R. W. Kolkka, MA	G Jitter
A. Agrawal, ME	Two Phase Fluid Dynamics
R. Boudreault	Materials Science and Manufacturing in Microgravity
R. Boudreault	Can You Really Use Space to Help Diabetics?
<u>Week 9</u>	
Jean Koster	Low G Science: A Challenge in Fluid Mechanics and Transport Physics
Jean Koster	Behavior of Fluids in Space
A. Hellawell, MY	Aspects of Materials Processing
John Perepezko	Drop Tube Experiments & Low-Gravity Simulation
John Perepezko	Containerless Processing in Space
<u>Week 10</u>	
Martin Glicksman	Solidification Experiments in Low-G Environments
Martin Glicksman	University Involvement in Space Programs
Wendell Mendell	Human Exploration and the Need for Space Resources
Wendell Mendell	Justifications, Policies, and Key Technological Problems for 21st Century Space Colonization
Class Project Presentations	

the visiting speakers. We also wanted participation from a number of different disciplines. Many faculty and students were skeptical initially about the course since they were unfamiliar with NASA's long-range plans and/or confused about the indecisive stance of the government and the populace towards the societal importance of space issues. A publicity campaign was mounted in which articles in campus and local newspapers, bulletins, and flyers described the course content. This campaign was devised to encourage student participation from the widest possible spectrum of engineering and scientific backgrounds. Our only selection criterion was that the student have upper level (senior or graduate student) status. The most effective aspects of the publicity was through word-of-mouth. These efforts of the course coordinator were essential in broadening participation and giving us a critical mass.

THE CLASS ITSELF

Special consideration had to be given to classroom logistics since the entire course was to be videotaped. Class lectures were held in a video-classroom complete with video-production equipment. Unfortunately, viewing conditions were compromised for the audience; the video-format forced the class to view slides and overhead projections on TV monitors rather than having these visual aids projected onto a screen for greater clarity. The small size of the room (30 seat capacity) also required any overflow audience to view the lecture in an adjoining room with a live video-feed. In addition, the opportunity to question/clarify points as they were raised during the class was precluded by the continuity required in the videotape. These compromises were necessary, however, if high quality videotape of the visiting lectures were to be obtained for use as a resource in future courses. A large lecture hall was employed for the evening presentations to allow for a larger community audience although the quality of the videotape was degraded. Often, more than 100 attended the evening lectures.

Table 2

Planetary Materials and Resource Utilization, Spring 1989
Invited External Speakers

John W. Alred. Exploration Studies Office, Code IZ2, Vangard Building, NASA Johnson Space Center, Houston, TX 77058: Lunar Base Study Systems; Bootstrapping; General Space Systems Engineering.

Richard Boudreault. Canadian Astronautics Limited, 1050 Morrison Drive, Ottawa, Ontario K2H 8K7: Microgravity Processing.

W. David Carrier. Bromwell and Carrier, Inc., P. O. Box 5467, Lakeland Florida 33807: Geotechnical; Mining; Civil Engineering.

James Blacic. Geophysics Group, Division of Earth and Space Sciences, MS C335, Los Alamos National Laboratory, Los Alamos, New Mexico 87545: Lunar Glasses.

Martin E. Glicksman. Materials Engineering Department, Rensselaer Polytechnic Institute, Troy, New York 12181: Solidification and Microstructures; University Involvement in Space Programs.

Jean Koster. Associate Director, Center for Low Gravity Fluid Mechanics and Transport Phenomena, Dept. Aerospace Engineering Sciences, Engineering Center, Campus Box 429 University of Colorado at Boulder, Boulder, CO 80309-0429: Microgravity Fluid Dynamics and Materials Science.

David McKay. Planetary Science Branch, Mail Code SN2, NASA Johnson Space Center, Houston, TX 77058: Space Resources Utilization; Lunar Oxygen; Lunar Materials Processing.

Wendell W. Mendell. Mail Code SN21, NASA Johnson Space Center, Houston, TX 77058: Space Resources Utilizations; Lunar Base Concepts.

John Perepezko. Metallurgical and Mineral Engineering, University of Wisconsin, Madison, WI 53706: Containerless processing; Simulation of Low Gravity Conditions; Drop Tube Experiments.

Ronald Sovie. NASA-Lewis Research Center, Mail Code 301-5, 21000 Brookpark Road, Cleveland, OH 44135: Lunar Power Sources.

Paul Spudis. Branch of Astrogeology, U. S. Geological Survey, 2255 N. Gemini Drive, Flagstaff, AZ 86001: Planetary Geology and Petrology; Lunar Origin Theories.

Lawrence A. Taylor. Dept. of Geological Sciences, University of Tennessee, Knoxville, Tn 37996-1410: Mineralogy, Geochemistry and Petrology of Lunar Materials.

James R. Zimbelman. Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institute, Washington, DC 20560: Planetary Science; Viking Results; Mars Geology.

Twenty-two students enrolled in the course; half were undergraduates and half were graduates from five different departments. Because of the nature of the course, no specific textbook was utilized although the outside lecturers supplied us with pertinent reading material and/or references. The students were encouraged to use the symposium volume "Lunar Bases and Space Activities of the 21st Century" (ref. 1) as background reading. These papers also served as models for the design projects (Table 3) which formed an essential part of the class requirements. The students were divided into six groups composed of four or five individuals. We selected the groups so that a diverse set of disciplines was present in each group, and an advanced graduate student (usually a doctoral candidate) led each design group; one or more of the internal faculty acted as advisors to each group. Each group was responsible for writing a paper using the format in the symposium volume as a guide and giving an oral presentation to their colleagues and faculty. The presentations and papers formed the basis of the assigned grades.

Students were asked to evaluate the class. They were very positive about the visiting lecturers (including the opportunity to interact with them), the topics that were covered, and the design emphasis. They were most critical of the uneven coverage, gaps, and overlaps that resulted from having a number of different speakers. The other problem was that because of the interdisciplinary nature of the participants in the course, some students (and faculty) were lectured on material they were already quite familiar with while others did not have an adequate background for certain topics. Although we worked from a logical course outline, we could not control the individual content of the lectures from both internal and external speakers. This sometimes led to obscure and frustrating transitions between speakers. With the videotape resource, the internal faculty are now in a much improved position. We are capable of designing and preparing the necessary introductory lectures with emphasis on terminology, fundamentals, and context, as well as constructing the bridges necessary to link the lectures of the external speakers. The design group experiences were particularly positive and overshadowed all of the minor problems.

SUMMARY

Although it required a concerted effort on the part of the core faculty and the coordinator, we believe that the objectives we had envisaged for the course were met effectively. The course will be offered in almost the same format this summer (1990) at an accelerated pace. We expect to add new, more specialized courses to the curriculum and to eventually establish a degree program in space-related engineering. Editing of the technical presentations of the external speakers is completed and these lectures are ready for distribution. Individual lectures are available and there are also "short course" groupings of lectures on topics such as: "Geology and Mineralogy of the Moon" and "Scientific Use of Microgravity". A condensed 10 hour short course version of these tapes is also planned.

REFERENCES

1. Lunar Bases and Space Activities of the 21st Century (ed. W. W. Mendell), Lunar and Planetary Institute (1985).

Table 3

Planetary Materials and Resource Utilization, Spring 1989
Class Design Projects

Purpose: Form small working groups in order to investigate a given design problem related to lunar base development. Use an integrated, multidisciplinary approach taking advantage of the individual backgrounds of each group member.

1) Define specific aspects of the problem
2) Determine appropriate requirements
3) Research background and principles
4) Propose solution

Goal: Prepare a concise paper modeled after those presented in Lunar Bases and Space Activities in the 21st Century, 1984, Lunar and Planetary Institute

Topics:

I. REGOLITH BRICK PRODUCTION

Most appropriate raw materials; brick design/geometry; production techniques; energy requirements.

II. SOLAR POWER SYSTEMS FOR MATERIALS PROCESSING

Direct (thermal) vs. passive (photovoltaic); furnace design; transport and assembly on lunar surface; site/geometry considerations.

III. LUNAR O_2: COMMINUTION

Bedrock (mining, fracturing, blasting) vs. regolith (particle size distribution, screening); maximum particle size requirements; dry milling and handling techniques.

IV. LUNAR O_2: SEPARATION AND CONCENTRATION OF ILMENITE

Distribution and form of oxide particles; dry handling; purity requirements.

V. LUNAR O_2: EXTRACTION OF O_2

Mineral chemistry; reduction reactions; hydrogen source; by-products; cryostorage.

VI. DEALING WITH DUST

Particle distribution; cohesion; filtration; abrasion.