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ABSTRACT

The Colorado School of Mines is in the 4th year of a comprehensive curriculum revision process. After refining the mission statement and graduate profile, the school has developed and begun to implement a new undergraduate curriculum which features design-across-the-curriculum, a sequence of "systems" courses, an enhanced and integrated humanities and social sciences component, and a distributed core. This paper describes the process and the products of the curriculum revision, including the methods for phasing in the new curriculum and ensuring that continuous improvement is built in to it from the beginning. (YDS)

A New Core Curriculum for Engineering and Science Programs at the Colorado School of Mines

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Abstract – At the Colorado School of Mines we are in the fourth year of a comprehensive curriculum revision process. After refining our mission statement and graduate profile, we have developed and begun to implement a new undergraduate curriculum which features design-across-the-curriculum, a sequence of "systems" courses, an enhanced and integrated humanities and social sciences component, and a distributed core. In this paper we describe the process and the products of our curriculum revision including our methods for phasing in the new curriculum and ensuring that continuous improvement is built in to it from the beginning.

Introduction

At the Colorado School of Mines (CSM) we are in the fourth year of a comprehensive curriculum revision process undertaken in response to concerns about systemic problems in engineering education [1, 2, 3]. To date we have developed a mission statement and a set of attributes which we wish all graduates of the School to achieve. We have also studied our curriculum and the curricula at other leading engineering schools and have developed and begun to implement a framework for a new curriculum which features design-across-the-curriculum, a sequence of "systems" courses, an enhanced and thoroughly integrated humanities and social sciences component, and a "distributed core." We are also developing a process for continuous assessment and improvement of our curriculum.

We are well on our way to developing, piloting, and fully implementing a unique undergraduate engineering program by the year 2000 which is consistent with the ABET *Criteria 2000* guidelines [4]. In this paper we focus on the framework of the new CSM core curriculum, describing the organization and content of key components, their connections, and their rationale in the light of the desired graduate attributes.

Colorado School of Mines and the Graduate Profile

The Colorado School of Mines (CSM) is a 123-year-old institution of engineering and applied science with a special focus on earth resources, the environment, and related fields. The School offers undergraduate through doctoral degrees in
chemistry, chemical engineering and petroleum refining, economics, engineering (with concentrations in civil, electrical, and mechanical), geological engineering, geophysical engineering, mathematical and computer sciences, metallurgical and materials engineering, mining engineering, petroleum engineering, and engineering physics. The undergraduate student body numbers approximately 2400, while the graduate school enrolls 800 students. Entrance requirements are among the highest in the U.S. for public institutions of higher learning.

After more than two years of discussion involving faculty, students, administrators, alumni, legislators, and the Board of Trustees, in 1994 the School adopted the "Profile of the CSM Graduate" (Appendix A) which contains those attributes that we believe our graduates will need in order to shape the world that we would like to see emerge in the next century. While the competency attributes in the CSM graduate profile predate the publication of the ABET *Criteria 2000*, there are striking similarities, and the result is a core curriculum which is consistent with the new directions of ABET.

Curriculum Features and Oversight

The revised curriculum is organized within a framework which has been designed to fulfill the highest expectations of the Colorado School of Mines' Graduate Profile. This framework is portrayed graphically in Figure 1, and it shows organizational blocks, some specific courses, vertical themes, and horizontal connections within the overall curriculum plan.

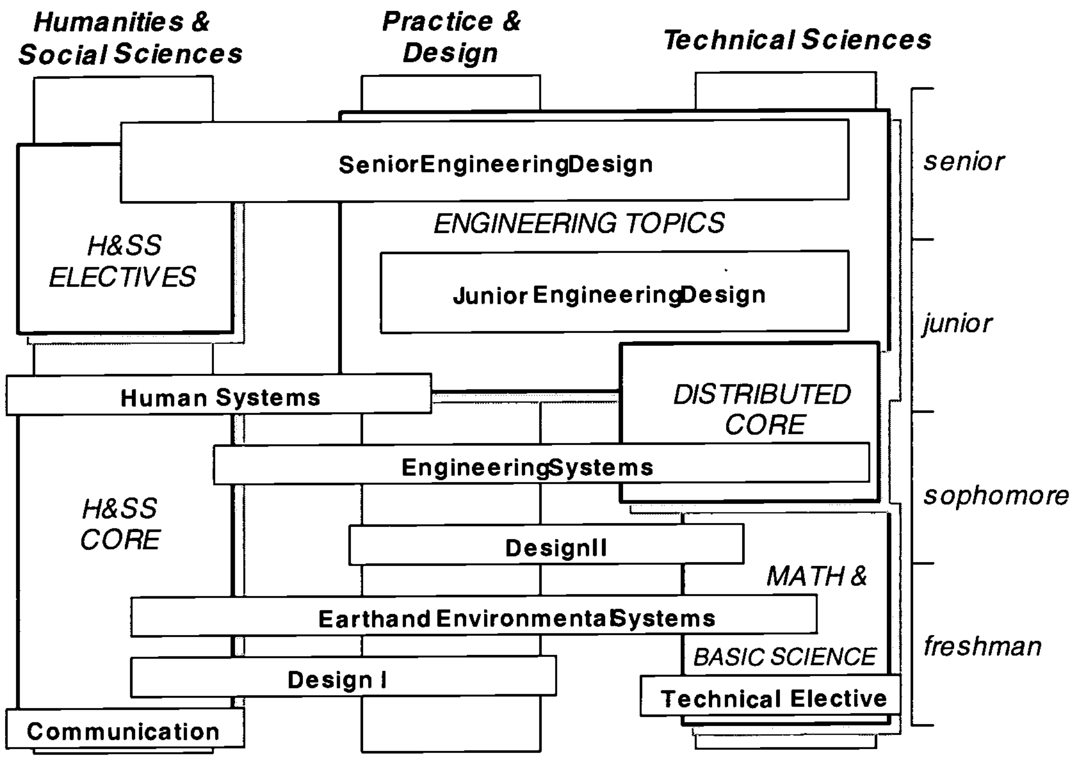

Figure 1. Colorado School of Mines Curriculum Framework

Underlying Principles

A number of principles underlie the framework depicted in Figure 1, including the following:

- revision of the current sequences in mathematics, physics, and chemistry, adjusting credits to be more in line with peer institutions and organizing syllabi to show the connections among the basic sciences and to preview their applications in the engineering sciences;
- revision and strengthening of the humanities and social sciences into a foundation-building multi-course core, providing thematic focus on the stewardship of the earth and contemporary public policy issues as they relate to technology and resources;
- a freshman writing-intensive course, rich in the foundations of writing skills and setting the stage for a freshman-through-senior writing across the curriculum program;
- a "stem" in engineering design from the freshman through the senior year, providing development in design, open-ended problem solving, teamwork, professional communication, and the use of technical knowledge in applications of increasing sophistication;
- a freshman-sophomore sequence which develops insight and introductory analytical abilities in the behavior of large systems, encompassing earth and environmental (natural) systems, engineering (manufactured) systems, and political and economic (human) systems; this sequence not only addresses the big picture and cross-disciplinary skills needed in modern engineering, but it also provides application contexts for the basic sciences and provides a bridge of relevance between lower division and upper division courses;
- a large block of engineering topics, encompassing both engineering sciences and engineering design pertinent to the award of a degree in a field of engineering; for science degrees, this block is correspondingly oriented toward specialty areas in the context of those degrees;
- clusters of distributed core courses, too focused for the entire school, yet broad enough to serve the prerequisite needs of upper division curricula in groups of related majors;

- a requirement to complete nine credit hours of free electives (not shown in Fig. 1);
- an optional and variable-credit freshman elective to satisfy and stimulate technical interest in the majors;
- a composite freshman course embracing physical wellness, counseling, and academic career planning (not shown in Figure 1);
- academic intensity in the freshman year contained in a reduced number of courses; and
- a purposeful attempt to improve retention through increased and newly designed opportunities for freshmen and sophomores to engage in technical interests; these opportunities include the freshman technical elective, discipline-oriented projects in the second design course, the use of applications-related problems in mathematics and the basic sciences, and contextual studies in the earth and environmental systems, human systems, and engineering systems courses.

In the sections below we will elaborate on some of the more distinctive features of the new curriculum—the design stem, the systems sequence, the humanities and social sciences program, and the distributed core.

Design

We define design as a complex, integrative and creative decision-making activity where one brings to bear information, skills, and values on an open-ended problem. Design is also an amalgamation of technical knowledge, process knowledge, research skills, communication skills, team skills and values, all in the interest of generating a product. The learning objective in the two-course core design sequence is to help students become more skilled in these activities. Because design is such a pervasive element in engineering, we see the need for continuous and mentored intellectual maturation in the practice of design throughout the curriculum. To accomplish our goals, we have planned a freshman through senior design stem.

Upper division students will be working in the context of their specialties; however, we see the need for students to learn and practice key design strategies in the first two years. Thus, we have implemented a two-part design stem building on the foundation of our well-established and widely-recognized EPICS (Engineering Practices Introductory Course Sequence) program [5]. In the freshman year, students are introduced to the design process by working on open-ended problems in teams and using computer software as a tool to solve engineering problems. The first course also emphasizes written technical communication and introduces oral presentations. The Design I course was implemented in 1997-98 and was generally highly evaluated by both instructors and students.

In the second (sophomore) design course, small groups of students will continue to solve problems for "clients," but each design class of 25 students will be devoted to projects in a particular field and will be coordinated by faculty with expertise in that field, e.g. environmental remediation, chemical processes, civil engineering. That way students who have not yet selected a major will be able to learn more about a field in which they are interested and departments can use their design courses to recruit students. In the Design II course, the skills to be enhanced are:

- Open-ended problem solving and decision making
- Learning how to learn
- The design process and being creative
- Teamwork
- Oral communication
- Written communication
- Gathering and integrating information
- Using software packages
- Graphical communication

Design II will be offered for the first time in the fall of 1998. In addition, all programs will offer design in both the junior and senior years, so that a student graduating from CSM will have experienced increasingly sophisticated design projects throughout the curriculum.

Systems

One of the key components of our revised curriculum is the three-course systems sequence. This sequence addresses the process and introductory knowledge for analyzing system interactions to predict the far-reaching consequences of decision or design. It also establishes a capacity for thinking about context and for reaching beyond the comforts of a discipline, shows how mathematics translates thought and descriptive behavior among disciplines, and demonstrates the presence and influence of natural laws in multiple settings. It also connects economic and societal driving forces to the engineering endeavor.

The systems courses are predominantly analytical and organized around themes which express how existing systems are composed and how they are analyzed. Because we believe that systems thinking includes the natural world, the engineered world and the human world, we are developing three courses in the systems sequence: Earth and Environmental Systems, Human Systems, and Engineering Systems.

The primary learning objective of the *Earth and Environmental Systems* course is to provide knowledge and understanding of natural systems and how humans interact with them. A key goal is for students to reach a level of sophistication with respect to these systems sufficient for them to produce engineering designs which are sensitive to natural processes. To meet this objective, the course is organized around the lithosphere, the hydrosphere, the atmosphere and the biosphere. Multiple themes build a systematic understanding in these areas; these themes include:

- The cycling of energy and mass
- Natural hazards
- Geography
- Global environmental change
- Natural resources
- Biodiversity
- Systems modeling
- Living with and managing natural systems

The *Engineering Systems* course, in contrast, has as its main learning objective the use of mathematical and scientific approaches in having students understand how the properties of matter, the sources of energy in nature, and the channeling and processing of information can be made useful to people in structures, machines, products, systems and processes. This objective is supported by the application of mathematics and science to the fullest depth possible, consistent with the sophomore positioning of the course. It is enhanced by case studies and the development of a familiarity with real world devices, materials and objects, including the properties, preparation and processing of materials. A central theme is the formulation of models to portray engineering systems, and the mathematical manipulation of these models to predict the behavior of such systems. This helps develop engineering judgment, a sense of expectation and a feel for approximation in dealing with engineering systems. A related theme is consistency of the analytical approach across traditional disciplinary boundaries. Finally, the interaction of engineering systems with their natural and socio-economic environments is included.

The third systems course, *Human Systems*, builds on students' prior experience in the humanities and social sciences, and is also intended to connect with the other systems courses. The goal of this course is to add comprehension of modern economic and political institutions from a systems viewpoint. Beginning with a review of systems in general, it analyzes how economic, political and cultural systems produce decisions and results at national, regional and global levels of organization. Students become aware of how the complex and dynamic relationships among economic, political and cultural systems, law and other sociocultural institutions shape policy. It makes them particularly aware of how interactions among governments, industries and other commercial enterprises, interest groups and the general public etc., work with regard to natural resource development and utilization, and how these interactions affect the environment.

The systems sequence spans three courses in the first and second years.

Humanities and Social Sciences

This part of the curriculum serves multiple objectives, fulfilling many of the attributes of the Graduate Profile, and providing consistency with CSM's mission as an academy for the stewardship of the earth. The general theme which has been proposed to support these objectives addresses *Human-Environment Interactions*. Within the scope of this theme, the curriculum will help educate students about the past, the present and the future. Its focus will be human-environment interactions including knowledge of how engineering responsibilities extend to consequences for human society and the rest of life on earth. With the exception of the principles of economics course, the proposed H&SS core courses are inherently interdisciplinary in orientation. Embedded in these courses are streams that pull content, cases, and illustrations from traditional fields such as anthropology, history and history of science, literature, philosophy, political science, and psychology.

The first course in the H&SS core, Nature and Human Values (NHV) was piloted during the 1997-1998 academic year. NHV is a required, 4-credit, writing intensive course. It was established to help students achieve several of the goals in the Graduate Profile, especially perspectives on the meaning, implications, and global context of "stewardship of the earth." NHV is premised on the fact that all human activity is inherently embedded in nature, that all human activity requires the "services" that nature provides. In this light, special attention is given to exploring the ethical responsibilities of engineers in meeting their chief duty—ensuring public health, welfare, and safety—as articulated in the principal codes of ethics of the engineering profession.

CSM also has goals for its students' achievements in communication and internationalization. Over the past year we have addressed the communications issue by hiring a Writing Program Administrator and two full-time writing instructors, renovating our Writing Center, developing a computer classroom for instruction in writing, and sanctioning a school-wide writing-across-the-curriculum committee. Nature and Human Values contains considerable instruction and practice in writing, particularly an introduction to technical writing. The Design I and Design II courses are also writing-intensive, as is Human Systems. In addition, each major is required to designate four of its courses as "writing intensive" and require these courses of its students beginning in 2000.

Meeting the internationalization objective is more elusive. Foreign language helps, but the realities of appropriate and qualified instruction are complicated, when all language instruction is delivered by adjunct faculty. The Office of International Programs is developing ideas to support international connections from upper division curricula.

The Humanities and Social Sciences sequence comprises two parts: three foundation building courses in the true core—Nature and Human Values, Principles of Economics, and Human Systems--supplemented by thematic clusters, each comprising three courses. Cluster areas are being organized around themes in Cultures, Ethics and Quality of Life; History, Law and Politics; Environment, Technology and Science; and International Studies.

Distributed Core

The CSM undergraduate degree programs span multiple technical areas, from economics through the mathematical and computational sciences, chemistry, and eight different engineering specialties. Not surprisingly, there are curricular requirements which are common to clusters of related programs. These requirements are neither true core, common to everyone, nor so specialized that they fall within the domain of a single program. In the past, many courses in this category have been delivered independently in different departments and divisions.

We have developed a group of courses which serve the needs of multiple departments which we call the Distributed Core. We see this as a way of not only improving delivery efficiencies and resource sharing across campus, but also as an excellent venue for emphasizing the cross-disciplinary impact of many topics of study.

We also see the Distributed Core as an important course evolution area, since it represents the interface between the true core and the variety of degree programs. Thus we hope that it will become an area where course structures are continuously negotiated and designed by all interested departments and divisions. These courses include those which cap the true core in a fashion which is germane to a cluster of degree programs, and those which set the stage for advanced courses in related specialties. This part of the curriculum is dynamic: as upper division programs evolve and change with time, the distributed core must adapt to provide appropriate cohesion with the true core. Among the Distributed Core courses currently under development for delivery in 1998-1999 are ones in thermodynamics, statics, fluids, computer programming, and circuits.

Implementation and Assessment

The overall framework for the new curriculum was approved by the faculty senate in early 1997 followed by formal approval by the Colorado School of Mines Board of Trustees. Pilot courses in the mathematics and basic sciences sequence, in the humanities and social sciences sequence, and in engineering design were delivered to some or all of the freshman class during the 1997-1998 academic year. In some cases, course substitutions for classes in the current catalogue were needed. We are now preparing for the full implementation of the new curriculum beginning with the class entering CSM in the fall of 1998. A new catalogue is being prepared and the freshman schedule is being reconfigured. While the implementation will move progressively through the freshman, sophomore, junior, and senior years, thus concluding in 2001, we have necessarily developed the structure and much of the detail for the upper division curricula in each degree-granting program. We have synchronized these developments with catalogue statements and assessment programs in accordance with the expectations of ABET *Criteria 2000* and of our own Graduate Profile.

At CSM we have been formally assessing the education that our students receive—both in the core and in their majors—for nearly a decade, first in response to a mandate from the Colorado legislature and more recently in response to regional and professional accreditation agencies in addition to our own needs [6]. We have concluded that the keys to successful assessment include involvement of faculty, development of an effective continuous improvement process, and use of assessment feedback to improve teaching and learning. Each program at CSM is currently developing its own assessment plan in concert with the CSM assessment committee. In each plan, programs are asked to identify their goals and objectives, define their performance criteria, indicate where in their curriculum students will have the opportunity to meet the objectives, devise appropriate methods for measuring outcomes, set a timeline, and develop an effective feedback loop. In addition, faculty developing each course in our new curriculum are asked to assess the course's effectiveness and report results and consequent changes before it is allowed to go beyond the pilot phase.

Conclusion

At the Colorado School of Mines we are well on our way to implementing a new core curriculum for our students. However, we realize that reform will only be successful if the curriculum is continually reviewed and improved. Therefore, we are developing a <u>process</u> to guarantee ongoing feedback at the same time we are developing our <u>product</u>, the new curriculum. We are piloting such feedback mechanisms as a quarterly newsletter to the entire CSM community which highlights curricular innovations; a series of faculty development initiatives such as teaching forums and "mini-grants" for faculty who want to develop or improve courses; annual retreats by departments to review and revise their curricula; and careful attention to the results of both programmatic and pilot course assessments. We believe that our efforts are leading to a change in campus culture and that curriculum reform at CSM will eventually be embraced, not as an activity that happens once a decade, but as an ongoing element of "business as usual."

Acknowledgement

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Appendix A

PROFILE OF THE COLORADO SCHOOL OF MINES GRADUATE

The Colorado School of Mines is dedicated to serving the people of Colorado, the nation and the global community by providing the highest quality education, research and outreach in all areas of science and engineering and associated fields related to the discovery, production and utilization of resources needed to become good stewards of the Earth and its resources. To do this, CSM must provide students with perspectives informed by the humanities and social sciences, perspectives which also enhance students' understanding of themselves and contemporary society. CSM is committed to the development of processes and approaches to mitigate environmental damage caused in the past by the production and utilization of minerals, energy and materials. It is also committed to minimizing such damage in the future, thus helping to sustain the earth system upon which all life and development depend.

- All CSM graduates much have depth in an area of specialization, enhanced by hands-on experiential learning and breadth in allied fields. They must have the knowledge and skills to be able to recognize, define and solve problems by applying sound scientific and engineering principles. These attributes uniquely distinguish our graduates to better function in increasingly competitive and diverse technical professional environments.

- Graduates must have the skills to communicate information, concepts and ideas effectively orally, in writing, and graphically. They must be skilled in the retrieval, interpretation and development of technical information by various means, including the use of computer-aided techniques.

- Graduates should have the flexibility to adjust to the ever-changing professional environment and appreciate diverse approaches to understanding and solving society's problems. They should have the creativity, resourcefulness, receptivity and breadth of interests to think critically about a wide range of cross-disciplinary issues. They should be prepared to assume leadership roles and possess the skills and attitudes which promote teamwork and cooperation and to continue their own growth through life-long learning.

- Graduates should be capable of working effectively in an international environment, and be able to succeed in an increasingly interdependent world where borders between cultures and economies are becoming less distinct. They should appreciate the traditions and languages of other cultures, and value diversity in their own society.

- Graduates should exhibit ethical behavior and integrity. They should also demonstrate perseverance and have pride in accomplishment. They should assume a responsibility to enhance their professions through service and leadership and should be responsible citizens who serve society, particularly through stewardship of the environment.

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