AN EARTH SCIENTIST VIEWS EARTH SYSTEM ENGINEERING

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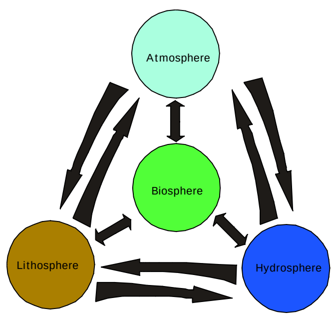
2002 Faculty Senate Distinguished Lecture – Murray W. Hitzman

This talk will address what the Earth system is and compare it to other planetary systems. It will discuss Earth System Science and what this discipline is from several different perspectives. I will then look at Earth Systems Engineering, a new field that is receiving attention from the National Academy of Engineering. I will try and demonstrate that what we really want to focus on is Earth Systems Science and Engineering — a new field which marries science, engineering, and the humanitites. I will conclude by suggesting that CSM should be a leader in this new field and suggest structural changes in our curriculum that may help us achieve this goal.

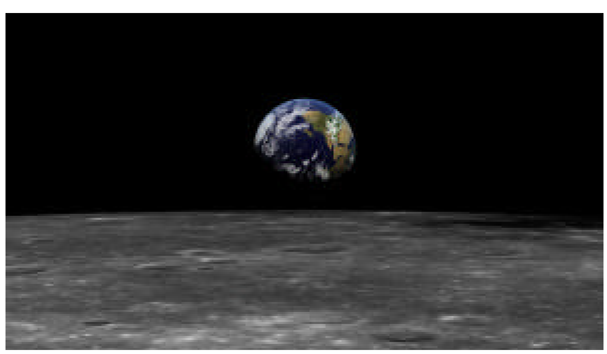
I would like to start by sharing with you a geologist's view of Earth and planetary systems.

Earth Systems Science has been a recognized field for a little over a decade. In its classical form, and as taught in CSM's own Systems Engineering 101 class, Earth and Environmental Systems, Earth Systems Science is defined as the interaction between different parts of the Earth – the lithosphere (or geosphere), atmosphere, hydrosphere, and biosphere. It is graphically described as:



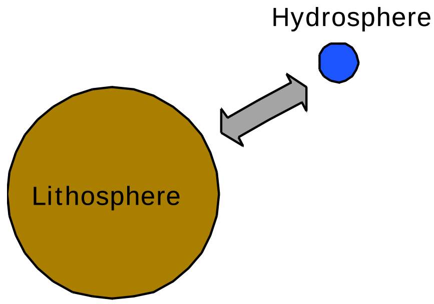
EARTH SYSTEM

This way of thinking about the Earth comes fundamentally from the space program and perhaps more than anything from images like this:



EARTH FROM APOLLO 17

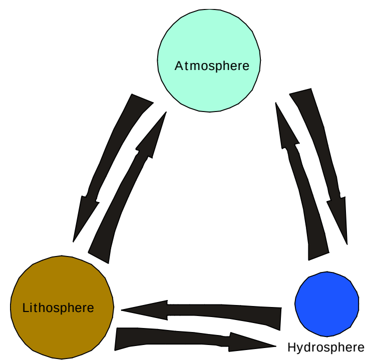
The space program opened our minds to thinking about planetary systems. The planet we focused on during the 1960's was the Moon. Moon System Science would look much different than Earth System Science:



MOON SYSTEM SCIENCE

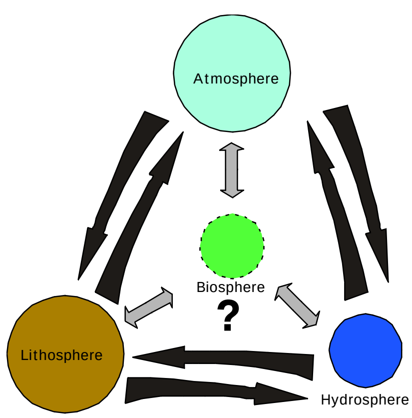
Unlike the Earth, the Moon obviously has no atmosphere and virtually no hydrosphere, though recent research suggests there may be minor frozen water at the poles (Binder, 1998). Our more recent fascination has been with Mars.

Mars Systems Science more approximately resembles that of Earth. The planet has an atmosphere and has a reduced hydrosphere represented by the polar ice caps and perhaps by groundwater in the form of permafrost.



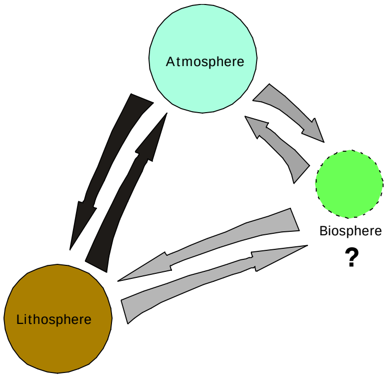
MARS SYSTEM

The real question of course is whether Mars has, or had, a biosphere.



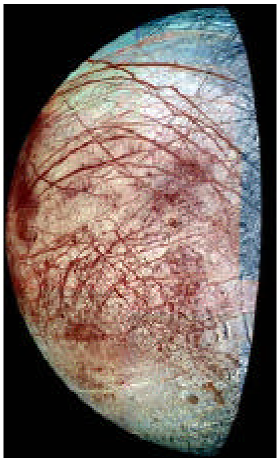
MARS SYSTEM WITH BIOSPHERE

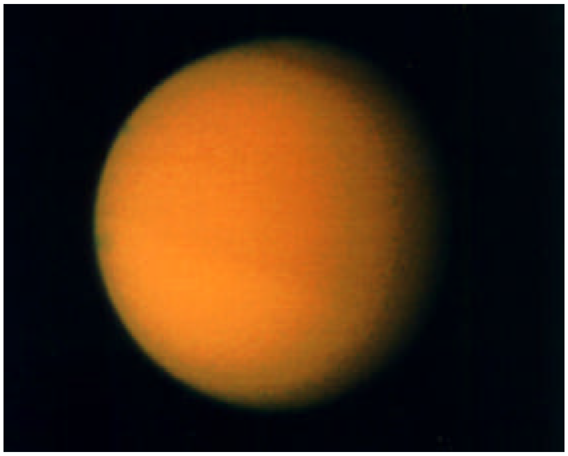
Venus presents us with another view of a planetary system. It has an atmosphere, a tectonically active lithosphere, but no hydrosphere due to its high surface temperature. Though many scientists are dubious of the prospects of life on the planet, suggestions have been made that life may exist within the atmosphere (Morton, 2002).



VENUS SYSTEM

We could continue this tour of the solar system and show that some moons of Jupiter, such as Europa, and of Saturn, such as Titan, may more closely resemble Earth with a lithosphere, well developed hydrosphere (largely frozen), a well developed atmosphere (in the case of Titan), and possibly a weakly developed biosphere.





EUROPA **TITAN**

However, the overwhelming, and scientifically obvious, fact is that earth is the only one of the planets in our solar system with a well developed biosphere. It is the only planet which reflects both blue and, more importantly, green light back out to the universe.

BLUE EARTH

The biosphere profoundly impacts the rest of the earth system. The chemistry of our atmosphere and our oceans is largely the result of approximately 3 billion years of life on the planet. While we think of life as confined to the surface of the planet, the more we learn about the Earth, the more we are forced to change our views. Over a decade ago, Thomas Gold (1992) suggested that more biomass resides as microbiological communities within rock in the upper lithosphere than on the entire surface of the planet. There have even been suggestions that some of a girl's best friends – diamonds – may be ultimately derived from subduction of organic carbon from life associated with black smokers into the mantle over millions of years (Etheridge et al., 1991).

BLACK SMOKER, SUBDUCTION, AND DIAMOND

These examples emphasize one of the central contributions of geology to earth systems science – the concept of geological time. The interaction of the biosphere with the rest of the earth system has been underway for possibly 3 billion years. Three billion years is a long time for a human to comprehend – though it is an instant in astronomical time. The light of many of the stars we see in the night sky is older – going nearly all the way back to the Big Bang 12 to 14 billion years ago.

DEEP SPACE WITH STARS

The concept of geological time is just as important to the history of science as Newton and his apple. The outcrop of shallowly dipping Old Red Sandstone overlying older rocks at Siccar Point, Berwickshire, Scotland provided the physician James Hutton in the late 18^{th} century, approximately 100years after Newton, with the clues about the antiquity of the Earth.

Hutton's observations led him to formulate the theory of uniformitarianism which states that the natural laws of chemistry and physics, and therefore Earth processes, do not change. Thus, what we see happening on Earth now has been happening in the past. Two hundred years of Earth science investigations have upheld this theory, though it is now realized that geological catastrophes, like asteroid impacts, have occurred throughout earth history and that while chemistry has not changed, the chemical makeup of the planet has evolved through time, in large part due to the influence of the evolving biosphere.

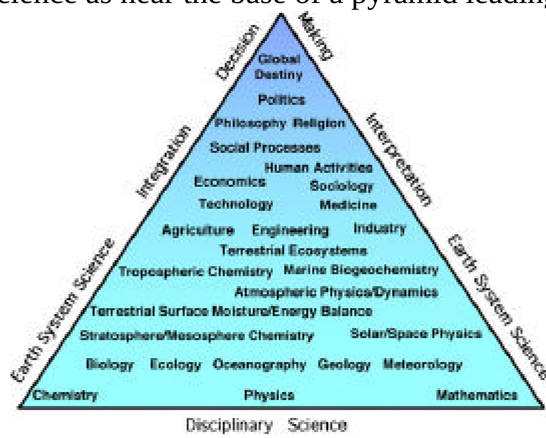
Another great Earth scientist, Charles Darwin, a generation after Hutton, applied the concept of time to biology by demonstrating the evolution of species over geologically short periods of time on the Galapagos Islands in the Pacific.

Even more recently in the timeline of scientific discoveries, the work of physical anthropologists and the development of geochronological techniques has shown that humankind developed several million years ago, probably on the continent of Africa. The remarkable diversity of language, culture, religion, and technology evident in the modern world developed in a geological instant.

This brings us back to Earth System Science as it is presently perceived. What is increasingly taught in earth system science courses, including the course here at CSM, is that not only does the biosphere significantly influence the earth system, but that one component of the biosphere, humankind, has a disproportionate influence.

The concept of Earth System Science is still poorly defined, however — I hope later to explain why I think this is so.. Some academic groups, like that at Queens College in Canada, view earth systems science as simply the natural sciences of the earth – geology, geophysics, hydrology, oceanography, atmospheric science. Other groups, like the Earth System Science Center at Penn State, are pushing the field toward the anthropocentric with the inclusion of economics and geography, along with the geosciences and meterology. A broader view of Earth

Systems Science has also been embraced by both NASA and NSF. Donald Johnson and others (2000) view earth system science as near the base of a pyramid leading to decision making.



JOHNSON ET AL. (2000) DIAGRAM OF ESS

The Cooperative University-based Earth System Science Education Program, which develops undergraduate Earth System Science courses at over 40 US universities suggests teaching modules such as the hydrological cycle and atmosphere, as well as remote sensing, energy budget, economic stability, and human health (Johnson et al., 1997). Note that the lithosphere, the physical Earth, is not on the list!

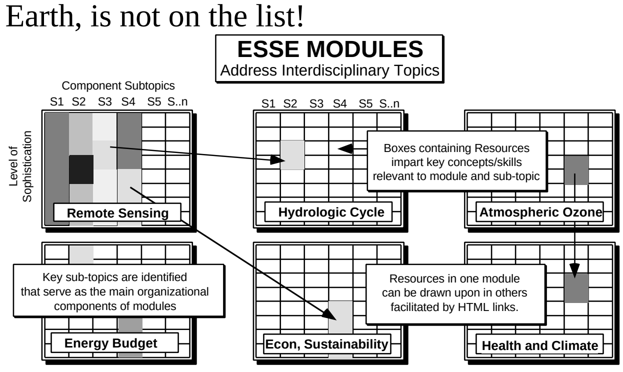
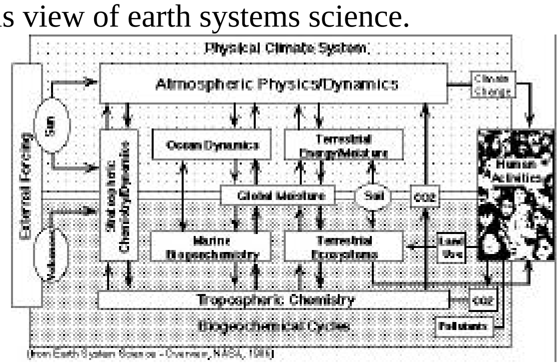


Figure 1

JOHNSON ET AL (1997) – ESSE MODULES

NASA has taken this even further. They see earth system science as almost totally what happens on the earth's surface and in the atmosphere. The physical earth is reduced to volcanic-derived gases and soils (http://www.usra.edu/esse/esseonline/whatis.html). A large portion of the "Earth" is missing from this view of earth systems science.



NASA (1986) VIEW OF ESE

This interpretation of Earth System Science is pushing the discipline directly into the sphere of global change as defined by Sigma Xi in 1994: "Global change is concerned with the nature and consequences of anthropogenic perturbations in the interacting physical, chemical and biological and social systems that regulate the environment supporting human life and influence the quality of life on planet earth." (Emphasis is mine)

As an Earth scientist I would fundamentally disagree with this definition of global change. To an Earth scientist, global change is a change in conditions of the lithosphere, hydrosphere, atmosphere, and/or biosphere through time due to any number of factors – near instantaneous asteroid impact, the slow buildup of oxygen in Earth's atmosphere over geologic time, the intermediate time frame recorded by the Holocene Ice Ages, or more recent anthropogenic climate change.

However, we are a self-concerned, somewhat selfish species looking, not surprisingly, on a human, not a geologic, time frame. We are concerned about changes that could directly affect us. To most people, global change is about short time-scale changes to the Earth, many of which are anthropogenic. This is where engineering comes in!

Science is defined by Webster's New World Dictionary (3rd Edition) as "systematized knowledge derived from observation, study, and experimentation carried on in order to determine the nature or principles of what is being studied."

Engineering on the other hand is defined as "putting scientific knowledge to practical use" or "the act of maneuvering or managing."

Science determines the how's and why's, engineering is the action of doing something with the knowledge. Or as Brad Allenby (2002) has written: "Science is concerned with what is; technology *(or engineering)* creates what will be." While many engineers are scientists, fewer scientists actually do engineering.

What I perceive as the fuzziness in Earth System Science is where it trends away from science and ventures into the area of action. We are beginning to confuse Earth System Science with Earth System Engineering.

Like Earth System Science, Earth System Engineering is seen differently by different groups. Here at CSM, the Mining Engineering Department offers graduate degrees in Mining and Earth Systems Engineering which includes civil, geotechnical, environmental engineering principles for rock systems and construction. At Columbia University, which has a Earth Engineering Center, the focus is on energy engineering, water management, and industrial ecology (http://www.seas.columbia.edu/earth/).

Earth Systems Engineering stems from "geoengineering" which was coined by Cesare Marchetti (1977) for a proposal to sequester carbon in the ocean. From this original usage the term evolved to describe the deliberate modification of biogeochemical and/or energy flows in the Earth system, generally focused on climate (Schneider, 2001).

The concept of Earth Systems Engineering emerged from geoengineering at the very end of the 20th century. Some researchers still focus on the climate-related elements of Earth Systems

Engineering. Dr. Stephen Schneider of Stanford defines the field as "the deliberate manipulation of the Earth System to manage the climatic consequences" (Schneider, 2001).

Dr. George Bugliarello of the Polytechnic University defines Earth Systems Engineering as "the engineering of the interaction of the Earth's inanimate organic components with the Earth's … biological organisms and societal entities and processes, and the artifacts (the machines) they have created" (Bugliarello, 2002).

One of the strongest adherents of Earth Systems Engineering, Brad Allenby of AT&T, defines Earth Systems Engineering as "the study and practice of engineering human technology systems in such a way as to provide the required functionality while facilitating the active management of the dynamics of strongly coupled fundamental nature systems" (Allenby, 2001).

The National Academy of Engineering has made Earth Systems Engineering a new focus. The Academy defines the field as "a new area of inquiry, stemming from the concepts of geoengineering, or human activity at the level of global systems" (http://www.nae.edu/nae/naehome.nsf/weblinks/NAEW-4NHMBR?OpenDocument).

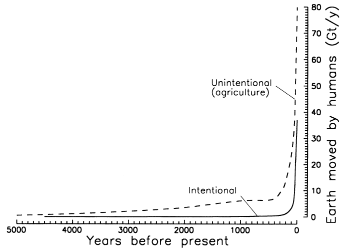
The National Academy of Engineering definition is perhaps the simplest and the broadest. Earth Systems Engineering is human induced change of the Earth system. It is nothing short of engineering the planet.

One could argue whether Earth Systems Engineering must be conscious or not. The National Academy of Engineering definition is silent on this point. Schneider (2001) argues that Earth Systems Engineering is the deliberate manipulation by humankind of the Earth system, while Allenby (2000) states that humans have been engineering the planet in a serious way since the deforestation of vast areas of the globe such as Europe two millennia ago. Bugliarello (2000) suggests that humans first produced widespread engineering though the domestication of plants and animals approximately 10,000 years ago.

There is no question that humankind is currently an agent of change in the Earth's system. A view of the nighttime surface of the Earth from space gives us an idea of the scale of our engineering. Earth is no longer just a blue and green planet, it is a planet of twinkling lights against the darkness that outline the continents – or at least some of the continents.

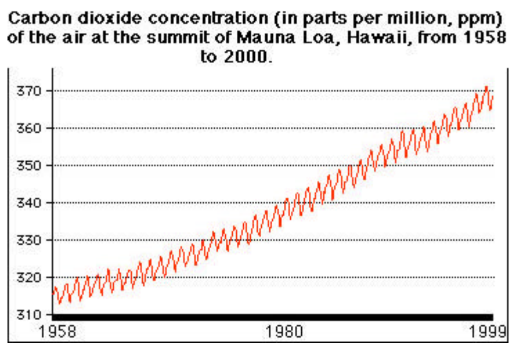
NIGHTTIME EARTH WITH LIGHTS

Hooke (2000) has argued that humans are currently one of the premier geomorphic agents sculpting the Earth's surface. Humans currently move approximately 37 gigatons of material per year intentionally and approximately 80 gigatons of material per year through unintentional means, primarily agriculture. He calculates that the total earth moved in the past 5000 years would be enough to construct a 4000m high mountain range, 40 km wide and 100 km long – essentially a good portion of the Front Range of Colorado!



HOOKE (2000) GRAPH OF EARTH MOVING

There also seems to be little doubt that anthropogenic agents are changing the composition of the atmosphere as seen by the classic graph of atmospheric carbon dioxide from Mauna Loa which helped to trigger the global warming debate (Pales and Keeling, 1965; Keeling et al., 1976).



http://cdiac.esd.ornl.gov/trends/co2/sio-mlo.htm

MAUNA LOA CARBON DIOXIDE RECORD 1958-2000

Humankind is also profoundly affecting surface and groundwater as well as the oceans. Humanity is currently using over 50% of the geographically accessible surface water runoff on the planet (Postel et al., 1996). Humanity's effects on fishing stocks in the oceans is well known, what is currently less understood is our modification of ocean chemistry and dynamics. A recent report on increasing river discharge into the Arctic Ocean, presumably due to climate warming, indicates that a large change in freshwater flux into the ocean could produce changes in ocean circulation which in turn could change climate in the North Atlantic region (Peterson et al., 2002).

Thus, humans are affecting, at a global scale, the lithosphere, the atmosphere, the hydrosphere, and we have certainly modified the biosphere in many ways that we do not fully understand. Humanity is re-engineering the planet, even if we have not, until recently, been quite conscious of the fact.

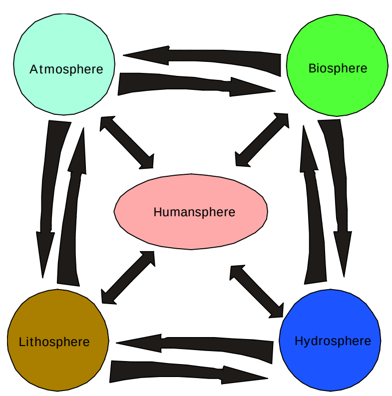
In some ways we are simply following the path of the bacteria. In the late Archean to Early Proterozoic, 2.5 billion years ago, bacteria, probably using dissolved ferrous iron in seawater as an electron donor, produced by-product oxygen that over half a billion years changed the chemical balance of the atmosphere of the planet. Through this atmospheric change, other fundamental changes rippled through the lithosphere, hydrosphere, and the biosphere. These bacteria were probably Earth's first major engineers. Humankind follows in their footsteps.

Some geoscientists and biologists suggest that these early bacteria poisoned themselves as oxygen levels built up in ocean water (Maynard, 1991). Like the bacteria, we may be fouling our own nest.

Why are humans now an agent of change of geological proportions? Simply put, it is numbers and ability. It took countless trillions of bacteria approximately half a billion years to change Earth's atmosphere. Life has been interacting with the planet for approximately 3 billion years. But three billion years is only approximately 60 million human lifetimes. The Earth currently holds 6 billion people.

ZAMBIAN CAR

We, as a species capable of sophisticated tool making, have the numbers to overcome time. I would argue that if we really look at the earth system, mankind now merits its own "sphere."



EARTH SYSTEM WITH HUMANSPHERE

This is why discussions of Earth System <u>Science</u> become muddled – we speak of the 4 spheres (litho, hydro, bio, and atmosphere) but an important new sphere is the human sphere. But how do we interact with the rest of the Earth system? Through our engineering!

We should call this new field Earth Systems Science and Engineering. To understand the Earth system we must understand our own place in this system. Like Schrödinger we cannot examine the system without disturbing it.

As Allenby has written, "The issue is not whether we should begin Earth Systems Engineering, because we have been doing it for a long time, albeit unintentionally. The issue is whether we will assume the ethical responsibility to do Earth Systems Engineering rationally and responsibly" (Allenby, 2000).

Thus, what I will call Earth Systems Science and Engineering verges into the murky waters of ethics and by extension, the whole arena of the social sciences and economics. Earth Systems Science and Engineering opens the Pandora's box of truly tying together humankind's knowledge.

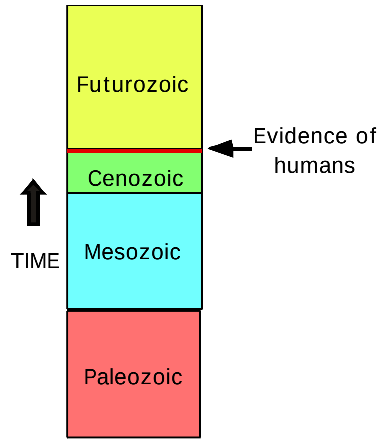
The example of global climate change, currently the most obvious focus of Earth Systems Science and Engineering, is instructive. While we are still far from truly understanding Earth's climate system, we are making rapid progress. Though we currently do not have the tools to consciously engineer climate, we have many end-of-the-pipe technological patches such as carbon sequestration and potential tools such as increased nuclear power or enhanced fuel cell usage.

While there are certainly daunting engineering hurdles, even more daunting are the economic, political, and social issues. The failure of the world to reach consensus on the Kyoto protocol is only a single, though instructive, example.

Thinking on an Earth systems scale opens many possibilities. A currently fashionable concept is that of sustainable development.

SLIDE OF QUOTE SUSTAINABLE DEVELOPMENT – "DEVELOPMENT THAT MEETS THE NEEDS OF THE PRESENT WITHOUT COMPROMISING THE ABILITY OF FUTURE GENERATIONS TO MEET THEIR OWN NEEDS." (WCED, 1987) "BRUNDLANDT REPORT"

But who will define what is sustainable? There are a wide variety of sustainable futures. If I look as an earth scientist I can easily envision Earth as a sustainable system no matter what humans do. Destroying humanity with nuclear weapons or bioengineering will not significantly affect the Earth system and will cause only relatively minor event, in geological terms, within the biosphere. Our passing would leave little more than a thin sedimentary layer in Earth's long history.



SLIDE OF SED SECTION WITH LAYER

However, if I look on sustainability as primarily an issue for humankind rather than the Earth system, a much different view presents itself. Our actions have profound implications for a sustainable environment for our species. If I become even more specific as an American, how do I design a sustainable future for our current lifestyle – one that could allow peoples in other countries to attain our standard of living?

Clearly these questions involve more than just a scientific or engineering viewpoint – they point to the heart of the social sciences and humanities – questions of culture.

I believe the emergence of the integrated field of Earth Systems Science and Engineering at the very end of the 20th century will eventually be looked on as a landmark in human history. It marks our emergence from ignorance. Humanity is now starting, albeit at a very slow pace, to understand the consequences of its actions and its technology. We have not yet learned to truly understand the consequences of our cultures – this will be the next great awakening and will probably trigger a revolution comparable to the industrial revolution and the information and biotechnology revolutions we are currently in the midst of.

Earth Systems Science and Engineering or ESSE is interesting in itself as an acronym. Esse is Latin for "to be." Esse is the root of "essence" and "essential". The birth of this field will allow humankind, perhaps, to find what is essential – the holy grail of philosophy.

As scientists and engineers we learn to test hypotheses, to build prototypes of our machines. As we move towards Earth Systems scale science and engineering how do we do this? After all, experimenting with the Earth system involves fundamentally changing or disturbing our physical environment and through it our social structures. It will take humanity time to discover the methods and tools to operate in this new, essential world.

I began this lecture by stating that the development of Earth Systems Science was directly tied to the understanding of our planet gained through the space program. I would argue that Earth Systems Science and Engineering will be tied in the technical sense to a continued and expanded space program. The world's current space program can be divided into three areas.

The first is deep space exploration exemplified by the Hubble telescope. The second is the examination of Earth conducted by many earth-viewing satellites and the space station project. This area is certainly capturing the majority of financial resources, as befits our self-absorbed species. The third area of the current space program is the exploration of the solar systems and the other planets. Here the recent focus has been the exploration of Mars, with a major goal being to determine whether a biosphere exists, or existed, on the planet.

As humankind wakes up to the implications of Earth Systems Science and Engineering, I believe this third component of planetary exploration will take on increasing importance. The inner planets, and Mars in particular, represents our next stepping stone outward. But even more important they provide us with the laboratory to really practice "Earth" or in this case Mars System Science and Engineering.

As scientists we test hypotheses, expecting many of our ideas and theories to be wrong. Engineers build prototypes of machines, commonly breaking the overall system down into simpler systems or parts.

We cannot consciously engineer parts of the Earth system without potentially cataclysmic consequences. Proposals to seed dust in the atmosphere to change Earth's albedo have been seriously proposed in the past decade (Govindasamy and Caldeira, 2000; Kellogg and Schneider, 1974) and we have undertaken several large scale experiments to seed the oceans with iron to increase productivity and thus sequester carbon in oceanic sediments (Martin et al., 1994; Watson et al., 1994). But even these relatively small-scale experiments have been met with doubt about our understanding of fundamental processes and therefore our ability to successfully predict consequences.

If we are to truly move towards planetary engineering we need a planet to practice on – one that is not our home. Thus, if we as a species, proceed down the path of conscious Earth Systems Science and Engineering, one of our next logical steps is to practice our engineering skills on Mars. Can we terraform a planet? Can we re-engineer its atmosphere, hydrosphere, and lithosphere, probably by creating a biosphere?

Of course, there will be serious ethical and cultural concerns with the fundamental change of another planet – particularly if Mars is found to have an existing biosphere.

Let me indulge in a flight of fancy here — Mars provides us with the opportunity to truly learn about planetary systems and to hone our skills at manipulating them. If we are successful on Mars, perhaps we will learn enough to have a go at Venus. After two other planets, perhaps humankind will know enough to begin large-scale, deliberate tinkering with our own home. Of course, if we are successful we may by then have two other planetary homes.

While this sounds like Star Trek science fiction, these are the vistas opened by a serious examination of Earth Systems Science and Engineering. Humans only 4 or 5 generations ago would not believe a man would soon walk on the moon and some of us alive today wonder at the "magic" of the information technology revolution and the Internet. We are approaching the ability to engineer new life – Craig Venter expects to accomplish it within the decade. We will be able to tailor living machines through bioengineering to help us engineer atmospheres and hydrospheres on a planetary scale on Mars and Venus.

But a fundamental question is – are we ready? The pace of change today is increasing. We are able to stimulate changes in decades that once took geologic time. Is our technology racing ahead of our ability as a species to comprehend it?

Clearly, though we are gaining the capabilities to technically manage Earth Systems Science and Engineering, our cultural abilities are lagging. As mentioned before, I believe the next great revolution for ESSE to be truly successful must be in the social sciences and humanities so that we as a species are better at collective decision making.

We are just at the beginning of this development. Interdisciplinary studies of technology management and humankind's groping forward in the area of global climate change are the first stirrings in this direction.

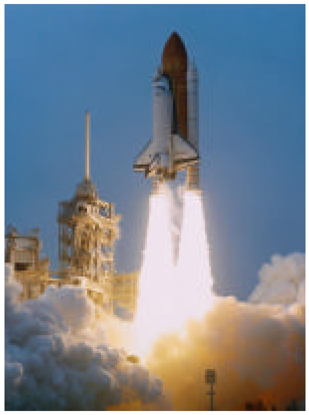
As we move towards greater sophistication and integration of the social sciences, our technological abilities outstrip our cultural ones. This is potentially a very dangerous time for us as a species – like a child with the ability to walk but not yet having the knowledge of fire or a sense of gravity down stairs. We must learn to control our technical hubris. As Frodeman and Mitcham (2003) have written, "The future is not something that simply happens to us; we determine our future through the choices we make."

Allenby (2000) has proposed a number of principles of Earth Systems Engineering that I believe apply even more directly to Earth Systems Science and Engineering. Paraphrasing these and grouping them into engineering principles I come up with the following list:

- ?? Only intervene when required and to the extent required.
- ?? Undertake smart engineering
    - o Know the objectives of any intervention from the beginning and establish metrics which can track progress and provide early warning of unanticipated system responses;
    - o Engineer changes in an incremental and reversible fashion;
    - o Focus on the development of resiliency, not just redundancy;
    - o Design inherently safe systems rather than engineered safe systems.
- ?? Look at the total design process
    - o Understand that the engineer is an integral component of the engineering system;
    - o Management and organizational skills are as critical to success as technological skills;
    - o Understand that design is inherently multi-dimensional and includes temporal and cultural components which must be accommodated if the design is to have social legitimacy.
    - o

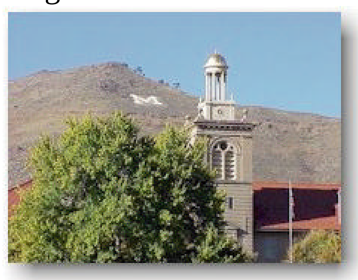
Are we capable of design in this manner? I would argue that we have had very little practice. The U.S. Apollo and the Space Shuttle programs approach these standards, but even though these were huge engineering undertakings, they do not reach the standard of true, conscious Earth Systems Engineering. As, unfortunately, we have recently seen, even these engineering ventures can fail catastrophically.

Francis Bacon summed up these thoughts about engineering succinctly long ago, "Nature, to be commanded, must by obeyed."




SPACE SHUTTLE

How will we train these engineers? Look around you, I think CSM can be one of the leaders in developing the tools necessary to begin the task. The school's mission statement from the State government is to have "a unique mission in energy, mineral, and materials science and engineering and associated engineering and science fields."

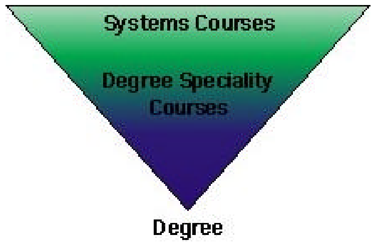


CSM

Colorado School of Mines, through its mission statement, aspires to be a center of Earth Systems Science and Engineering. Though not generally thought of in this way, this is why all undergraduate students at the school take Earth and Environmental Systems. We use this course as a foundation. Perhaps instead we should think of this topic as a capstone subject – or offer a reprise course that really focuses on Earth Systems Science and Engineering taught by a broader cross section of the faculty.

Like many engineering schools, CSM currently provides our students with the scientific knowledge to understand conventional engineering. We provide core engineering classes to help our students understand the breadth of possible engineering enterprises. We have EPICS and our capstone courses to allow the students to work in teams and focus on individual engineering problems. We currently require, as per ABET, our students to gain an appreciation of culture through LAIS and Economics.

However, like many schools, we fail at tying the whole package together. This stems from many factors. It is difficult for students to truly integrate when their college career is an inverted pyramid moving from general systems classes to the highly specialized knowledge of each degree program.



CSM DEGREE PYRAMID

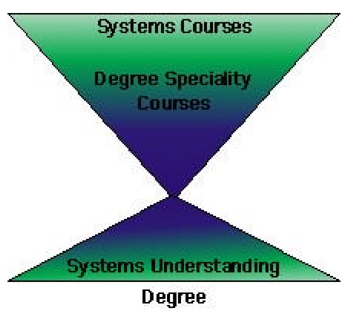
With some exceptions, such as the Materials Division, our departments are, by and large, very focused into relatively narrow, specific areas.

This has been brought home recently by the difficulty of motivating groups in different departments to mobilize towards President Trefny's focus areas of energy, natural resources, engineering pedagogy, computing, and environment.

The school is currently moving into another round of curriculum reform – brought on in large part because our faculty believe they see better ways of teaching, but also driven by a probable mandate from the State for less credit hours per degree and the present budget situation.

I would like to take this opportunity to add my two cents worth to the debate – through the prism of trying to train individuals who will be capable of thinking about, and moving forward humankind's abilities for Earth Systems Science and Engineering.

There is no question that our students need the basics of science – mathematics, physics, and chemistry – to function in a technological environment. The Freshman year will probably always be about ensuring a basic scientific literacy. However, after Freshman year, students must begin the integrative process with an exploration of specific fields. This integrative process should lead them to their Senior year where they can once again broaden out and see how the pieces of their entire four years fit together.



CSM DEGREE DIAMOND

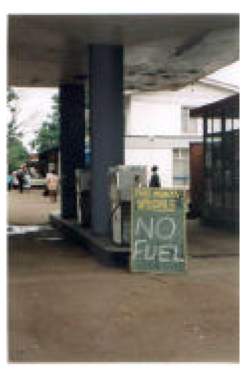
Rather than just the degree-specific content we now provide, we should also weave through this process cross-cutting skills in three fields – environment, culture, and biology. Each of these three areas are critical if we are to develop true Earth systems engineers. Our students require an appreciation of the complexity of environmental aspects of their specific brand of engineering. Integrating environmental management into any of the disciplines – even mathematics – will provide students with an appreciation of truly complex and interconnected systems.

SLIDE OF PHOTO OF MWH IN NEW GUINEA

Cultural understanding is critical for all engineers. Not just good communication skills that will provide them with one of their most important skills for getting that well paying job, but an understanding of human cultures and the place of science and engineering in those cultures. We at CSM are not doing a good enough job in this area – this is not surprising. I am not aware of any institution of higher learning that has cracked this nut. Many of our students are becoming scientists and engineers because they look down on the "squishy" social sciences. We need more social scientists on the faculty with a focus on science and technology and their roles in various cultures. We then need to work with these faculty members to develop pedagogical techniques to ensure the marriage of the social and hard sciences and to develop an appreciation in our students that engineering is only conducted within a cultural context. This will not be easy. One mechanistic means of making this happen in the short term may be to put a social scientist in each of our disciplinary faculties.

The third cross-cutting area is biology. While biology is a basic science, its inclusion as a cross-cutting area is appropriate at this time in history. We are in the midst of an incredible revolution in the biological sciences and bioengineering. The recent completion of the human genome project is only one, relatively small, example. Humankind has sufficient tools now to manipulate life. From cancer treatments to genetically-modified organisms to cloning we are truly living on the edge of a brave new world.

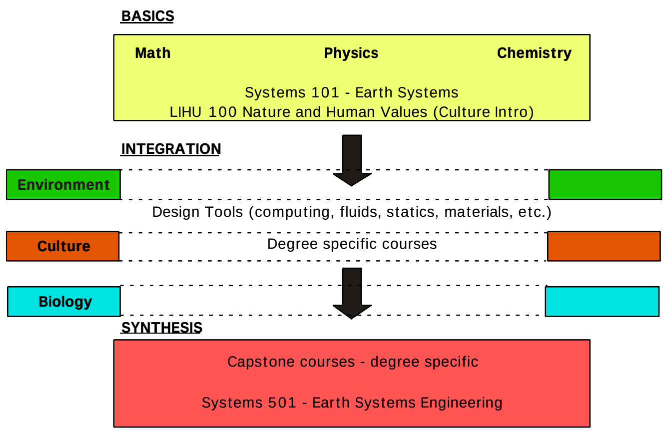
Technically-oriented students today, in whatever field of science or engineering, need an appreciation of the biosciences from bio-engineered life forms that will be able to produce specific compounds and materials to the utilization of micro-organisms to ensure maximum petroleum production from an oil reservoir. Judicious use of biology may help us avoid signs such as this.



ZAMBIA – NO FUEL SPECIAL

Every one of the fields being taught at Mines today is being impacted by biology – even if we as an institution are not participating. Our students must be given the basic tools to survive in the rapidly arriving bio-engineered world.

On a pragmatic level we will have to work to ensure that these three areas – environment, culture, and biology – do crosscut through all our degree programs. We may be close to having sufficient staff to accomplish a cross-cutting curriculum in environment. Many of our faculty in different departments work on environmentally oriented projects and we have the faculty of the Environmental Science and Engineering Division.



CSM DEGREE WITH CROSS-CUTS

We are understaffed with respect to culture. However, less than 10 new hires might provide the critical mass necessary to integrate a study of culture throughout all our degree programs. Given the current budget situation, it is unlikely that we can rapidly provide what is needed for our students in biology. The BELS program is a good first step, as are partnerships with local institutions and hospitals, but we need to start planning now how to ensure that all Mines students have some appreciation of this field.

Note that none of the three areas need form its own department – though they may. We need to develop a strategic plan for hirings that will place at least one environmental and bio-scientist or engineer, as well as one social scientist, in each department. These cross-cutting areas, linking all our disciplines, could be virtual departments with individual faculty spread among the departments.

The Earth Systems Science and Engineering paradigm requires integration of disciplines and knowledge bases – not just in science and engineering, but also in the social sciences if we are to truly train the leaders of the future.

I am sure to many of you what I am proposing sounds like a large amount of added materials for our students to learn. How can this be done if we are to limit the number of credit hours required for a degree? We need to seriously examine what we are teaching our students and pare down the basics in science and engineering while adding from the social sciences area. Our students are more adept at using the Internet than we are. They can find information more quickly and efficiently. The problem is in their determination of which information is good and which is bogus. We need to give them the tools to think – to make these determinations. There is no question that there is much much more knowledge than we can teach in four years. What is the right menu of basic knowledge in science, engineering, and culture that will allow them to critically examine information and will provide the basis for life long learning and wise stewardship of the Earth?

The final, Senior year at Mines is currently devoted to capstone courses. This is the right idea but we must examine if these courses really accomplish what should be the goal of the final phase of undergraduate education – synthesis. I teach a portion of an capstone sequence and I am sure it is not as focused on synthesis as it should be. We need senior level courses that truly draw upon the basics, that require integration of technical and non-technical (cultural) knowledge and experience to reach a synthesis.

Should such a course, or courses, be aimed at "completing" a student? The answer must be a definitive "No." We cannot provide all the knowledge necessary for our students in four, or even five, years. The Senior level courses should allow students to synthesize data but should also teach them that there is much more to learn – that learning is life-long and includes both technical and experiential data.

Integration and synthesis, the role of Earth resources in the broadest sense, a view both backwards and forwards to see where Humankind has been, how we got here, and where we may be going – these are what CSM's mission from the State of Colorado embraces. As an Earth scientist, I am proud to be at a institution that has a chance to be a world leader in Earth Systems Science and Engineering – the next great integrative challenge for humankind.

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