Syllabi, Proposals, and Work-in-Progress

Larry Goldberg, Ph. D.

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Contents

Preface

The writing in this volume is compiled to provide a feeling for my recent work and current research direction. Part I contains several syllabi that were written on contract to launch a new global change program, as well as several others prepared for my own philosophy courses. Part II contains a number of proposals, several of which were written on behalf of interdisciplinary programs or institutions in a coordinating or facilitating capacity. Part III contains the first chapter of a book I am writing on "The Science and Philosophy of Global Change." These miscellaneous writings are intended to supplement the accompanying volume, a second edition of my doctoral dissertation on complexity, explanation, and interdisciplinary cooperation in climate modeling. The appendix of the latter volume contains reprints of additional papers and publications.

Larry Goldberg, Ph.D.
Palo Alto, January 1996.

Part 1

Selected Syllabi

1.1

Syllabus

Geosciences 689

Global Change: Problems of Methodology, Policy, and Communication [*]

1. Short Description

In order to provide a shared frame of reference for students with diverse backgrounds, the course will begin with a review of the basic features of the earth from a systems perspective, with an emphasis upon climate, environmental chemistry, and their interactions and coevolution with life. Cosmic and solar contributions to earth's climate and chemistry will be considered, as well as the transfers of mass, energy, and momentum among the atmosphere, oceans, cryosphere (snow and ice), lithosphere (land and ocean floor), biosphere, and mantle (the molten stuff beneath the lithosphere). To complete our analysis of the causes of global change, the possible contribution of adaptive (or not so adaptive) mechanisms–of bacteria, unicellular eukaryotes, plants, fungi, animals, and human society–to the environment will be explored.

We will then go on to review major approaches to modeling global change for the special case of climate modeling. We will compare the purposes, methods and limitations of radiative, radiative-convective, energy-balance, general circulation, and statistical models of climate change. Models of environmental chemistry, agricultural or natural ecosystems, technological or economic activity, and the evolution of life, for example, will be considered only to the extent that they are coupled with global climate models. A variety of modeling problems will

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[*] This syllabus was prepared by Dr. Larry Goldberg for the Department of Meteorology and the College of Geosciences and Maritime Studies at Texas A & M University. The syllabus was approved by the Department of Meteorology as a potential graduate course offering in December 1993.

be considered, including those associated with limited and uncertain data; errors introduced by methods of numerical approximation used to solve a model's equations on a computer; inadequate understanding of many relevant phenomena; the difficulty of mathematically describing complex interactions among phenomena defined at different spatial or temporal scales; the need to approximate the effects of many phenomena that are not represented explicitly in a given model; and the statistical interpretation of model results.

The survey of climate models and their problems will provide the basis for a consideration of how such models, together with models of the biological and social consequences of climatic change, can contribute to informed environmental policy-making. We will explore a variety of approaches to policy analysis that associate predictions of potential impacts or consequences with alternative policy options. Some predict potential impacts on the interests of particular groups, others lump the interests of all groups in multifaceted scenarios, and still others make only relatively certain impact predictions that are taken to be indicators of environmental or social outcomes. We will consider the uses and limitations of such methods in particular policy-making contexts (e.g., energy, transportation, agriculture, and land and water resource management). Problems associated with uncertainty, the difficulty of comparing impacts on interest groups of different size, tensions between private interests and social values and between social and ecological consequences, and the difficulty of coupling what can be predicted with what people care about will be explored.

The course will conclude with an analysis of the ways that scientific visualization (e.g., movies of the outputs of global change models), information management (involving user-friendly access to large databases), and electronic communication (allowing more efficient communication across disciplinary boundaries and better student and public access to scientific information) can contribute to progress in global change research, planet management, and environmental education.

2. Prerequisites

Although this course is designed for College of Geoscience graduate students, graduate students in any other Texas A & M department or college (e.g., Biology, Chemistry, Political Science, Philosophy, Agriculture and Life Sciences, Architecture, Engineering) who have interests in environmental science, policy, and/or communication are most welcome to register. Undergraduates with strong science backgrounds may also register with the instructor's consent.

3. Requirements and Texts

Students will be required to write one thirty-page paper or, alternatively, to complete the development of a database, model or set of models, a policy analysis, or other approved project. Both papers and projects will be accepted any number of times for critical review in the course of their development. All topics for papers and projects will be chosen by students in consultation with the instructor. Attendance and class participation are expected and will contribute in unpredictable ways to all grades. E-mail accounts will be set up for all students, who will be expected to communicate with the instructor and with each other to exchange ideas.

Texts will include **Earth and Cosmos** (Robert S. Kandel, Pergamon Press, 1980); **Modeling the Earth System** (Dennis Ojima, ed.; UCAR/Office for Interdisciplinary Earth Studies, 1992); **Climate Change: Science, Impacts, and Policy** (J. Jager and H. L. Ferguson, eds.; Cambridge University Press, 1991); **Healing the Planet** (Paul and Anne Ehrlich, Addison-Wesley, 1991); and **Earth in the Balance: Ecology and the Human Spirit** (Vice President Al Gore, Penguin Books, 1993). Other materials will be distributed or made available over the campus network during the course.

4. Background

Global science, the interdisciplinary study of the interactions among climate, environmental chemistry, geophysical phenomena, and life–at all time scales–has as a focal research problem the simulation of past global change and the prediction of future global change. The problem of modeling global change is a challenge to scientific methodology not only because many of the relevant processes are not understood, but also because the complex interactions among phenomena defined at different spatial and temporal scales are difficult to represent mathematically–and the systems of equations that are developed to describe them are difficult to solve by numerical approximation on computers and to confirm with limited data. Moreover, many disciplines often must contribute to the development of global models, yet the interdependence of the phenomena they respectively study often doesn't allow multidisciplinary strategies of modeling subsystems separately for subsequent integration into an earth system model. The cooperative development of global models by many disciplines often requires agreement as to methods that cut across physical, chemical, biological, and social science disciplines–and this is not easy to achieve. The challenges of interdisciplinary modeling of global change also involve complex transfers of information between mother disciplines and the modeling subdisciplines they spawned as well as among the meteorologists, atmospheric and ocean chemists, oceanographers, glaciologists, geologists and geophysicists, ecologists and marine biologists, cloud physicists, radiative physicists and chemists, geographers, and social scientists, for example, who may contribute directly to model development.

Models of global change often have great policy implications, as in the case of predictions of the consequences of a greenhouse warming with evident implications for national and international energy and agriculture policy. Yet there often are great difficulties in moving from environmental change–e.g., climate change–to biological consequences for natural and artificial ecosystems, to social and economic consequences, and finally to the implications of predicted environmental, biological, and social impacts for the interests of various groups and the social values of a given society. Each of these couplings presupposes a selection of prediction goals on the basis of their biological, social, or policy-making relevance as well as the sensitivity of defined biological, social, or value dimensions to the predictions that can be made. The need for multiple levels of adjustment between prediction and impact dimension definition suggests the importance of sophisticated forms of collaboration and communication, as well as the need to negotiate a scientifically and socially acceptable methodology that integrates impact modeling and policy analysis.

Global change is perhaps the one theme that is guaranteed to provide an area of ultimate concern shared by all nations at any stage of development. The understanding of global change speaks to our shared history and destiny on earth. The advance of this understanding will depend on the ability of scientists and the public to communicate effectively with one another, as well as the ability of scientists to communicate across disciplinary boundaries with specialists in many different fields. Recent developments in scientific visualization, information management, and electronic communication promise to make important contributions to these communication challenges if they are utilized to best advantage.

5. More Detailed Course Description

To establish a common frame of reference for students with diverse backgrounds, the course will begin with a review of the earth subsystems that contribute to global change. These include the atmosphere, oceans, cryosphere (snow, glaciers, sea ice, and continental ice sheets), lithosphere (the solid land surface and ocean floor), the biosphere (all life), and mantle (the hot molten stuff inside the earth that slowly circulates, causing continental drift, sea floor spreading, and volcanic eruptions). We will trace the major interactions within and among these subsystems, including their reflection, absorption and emission of radiation; the transport of matter, heat and momentum by many scales of motion within the atmospheric and oceans; chemical reactions in the atmosphere and oceans, on the land surface, and in the soil; erosion by winds, rivers, and glaciers; the evaporation/transpiration–cloud formation–precipitation cycle; photosynthesis and respiration; growth and decay; the carbon cycle and other biogeochemical cycles; the subduction of sediment and outgassing of volcanoes; and the technological activities of humans. The contribution of external factors– such as changes in incoming solar radiation, asteroid impacts, and the orbital relationship between sun and earth–to the earth's climate and composition will be reviewed. Aspects of the coevolution of climate, environmental chemistry, and life will be explored, with particular attention to the evolved dependence of life upon a narrow band of terrestrial conditions as well as the possible adaptive control of certain environmental conditions by life.

After establishing a shared earth system science perspective, the course will go on to review many of the scientific problems confronted by global change researchers and environmental policy issues confronted by society–and explore, compare, and evaluate representative methods and styles of mathematical modeling, policy analysis, and scientific communication. Since climate modeling is undoubtedly the most developed form of global modeling, our survey of modeling methods will focus on ways of modeling climatic change. We will consider models of atmospheric and ocean chemistry, natural and artificial ecosystems, technological activity, and biological evolution only to the extent that they are coupled with global climate models.

In particular, we will distinguish among radiation models (that represent vertical transfers of energy), radiative-convective models (that couple vertical radiative transfers and vertical convective transports of heat), energy-balance models (that represent the coupling of the vertically averaged absorption, reflection, and transmission of radiation and the horizontally averaged transport heat by the atmosphere and oceans), general circulation models (that compute atmospheric and oceanic motions from the analysis of the forces that cause these motions at many grid points in a three dimensional array); a variety of statistical and stochastic alternatives to general circulation models; and related models of vegetation, soil, and projected human activity. Various problems of prediction (or simulation of the past) will be considered, including: the errors introduced by incomplete and uncertain data; the errors introduced by numerical approximation schemes used to solve the equations of a model (for a series of time steps) on a computer; the neglect or inadequate treatment of processes that are incompletely understood (e.g., the contribution of clouds, small-scale turbulence near the surface, the deep circulation of the oceans, glacial surges, or the response of vegetation to changes in climate and environmental chemistry); the difficulty of approximating the effects of phenomena that are too "small" or short-lived to be resolved by a particular model; the difficulty of mathematically representing the mutual interactions of phenomena defined at different spatial scales; the difficulties of confirming models in the context, for example, of simulations of the distant past, incomplete or uncertain data, or predictions of futures that may be associated with unanticipated external conditions (e.g., asteroid impacts) or internal states (e.g., atmospheric or ocean circulation regimes for which certain model assumptions have not been tested); the issues surrounding the statistical analyses of model outputs for comparison with real data (e.g., issues regarding the choice of spatial and temporal averaging schemes, the importance of predicting variability as well as change, and the statistical analysis of many model runs from feasible initial conditions).

After a comparative and critical review of global modeling methods, we will go on to explore how models can be used to predict biological or social impacts associated with alternative policy options. Different methods of policy analysis will be reviewed, ranging from the most analytical predictions of impacts on the concerns of different interest groups associated with various policy options to the most synthetic considerations of “scenarios” for each policy option that integrate many dimensions of social concern. For each type of policy analysis, we will consider a variety of issues of justification that can arise. For example, what do we do if scientists or experts can predict with reasonable confidence impacts that are not of the greatest social concern, but can predict only with far less certainty the consequences of policy choices that are of most social concern? How do we integrate potential impacts on different groups to determine what is good for the society? One person–one vote? Then what about impacts on minority groups, such as the impacts of climate change on the owners of farms in developed countries or the impacts of the ozone hole on people who get skin cancer? How do we compare economic impacts on particular groups with the destruction of ecosystems or the extinction of species? Is the good of a society just the “total” good of it’s citizens? How do we compare economic impacts on a nation with impacts on other nations? On future generations? How do we evaluate the importance of uncertain impacts? Should we be concerned only with probable futures or also with unlikely, but possibly devastating, futures? How can models best be developed to integrate what scientists can predict with what citizens and policy makers need to know (or should know)?

After assessing just how global change research might contribute to environmental policy–at regional, national, and world levels–we will go on to consider some of the social changes that will need to occur to make the shift to planet management and global responsibility possible. In particular, we will focus on three transitions in communication that are sure to play important roles. One is the enhanced communication among scientific disciplines that is prerequisite to the interdisciplinary collaboration required to solve many problems regarding global change. A second is the enhanced communication among university departments that is prerequisite to the development of interdepartmental programs needed to educate students for careers in global change research and informed global citizenship. A third is the enhanced communication between science and the public that will be needed for an authentic shift in both our social and our scientific values toward more interest in global problems. We will consider how all of these communication challenges might be facilitated through the timely development of well-managed databases with user-friendly interfaces, greater reliance on scientific visualization (such as colorful movies of model predictions), and the development of national and global information highways. The course will conclude with an assessment of the potential for scientific progress in global change research, social progress in environmental education and the emergence of global values, and political progress in planet management.

6. Course Outline

Week 1. **The Earth in Space**

- The sun and its electromagnetic spectrum; the earth and its internal heat.
- Origin and evolution of core, mantle, lithosphere, oceans, and prebiotic atmosphere.

Week 2. **Environmental Evolution**

- The origin of life.
- Photosynthesis, carbon dioxide, and climate.
- The origin of eukaryotic and multicellular life.
- The origin of the cryosphere.
- The climate system: atmosphere, oceans, cryosphere, lithosphere, and biosphere.

Week 3. **Transfers of Mass, Energy, and Momentum**

- Radiative transfer: reflection, absorption, emission and the electromagnetic spectrum.
- Scales of atmospheric and oceanic motion; the general circulations of the atmosphere and oceans.
- The sun and climate change; the cryosphere and climate change.
- Evaporation, transpiration, cloud formation, precipitation, and soil moisture.
- Chemistry and climate; biogeochemical cycles.

Week 4. **Climate, Chemistry, and Life**

- The effects of climate on life and human society.
- The Gaia hypothesis: the possible adaptive control of climate and environmental chemistry by life.
- The effects of human technology on the climate and environmental chemistry.

Weeks 5. **Models of Global Change**

- Climate models: radiative, radiative-convective, energy-balance, general circulation, stochastic, and statistical models.

Week 6. **Coupling Models of Climate Subsystems**

- Defining climate over years, decades, centuries, millennia, etc.
- The selection of a modeling strategy for a given purpose.
- Gaps in our knowledge: Clouds, turbulence, glacier dynamics, deep circulation of the oceans, feedbacks from vegetation changes, etc.

Week 7. **Approximation Strategies**

- Asynchronous coupling schemes for integrating models of climate subsystems. Trade-offs between detail and computability.
- Parameterization: The representation of the consequences at resolved scales of the mutual interactions between explicitly modeled and unresolved or otherwise neglected phenomena.
- Deterministic vs. statistical or stochastic approaches to prediction and modeling.

Week 8. **Confirmation**

- Need data not used to develop model. Independent degrees of freedom.
- Descriptive confirmation of parameterizations.
- Predictive confirmation of model as whole.
- Consistency with theoretical understanding of unresolved or otherwise neglected phenomena.
- Explanatory value: Sensitivity studies.
- Interdisciplinary value: Solution of interdisciplinary problems.

Week 9. **Impact Modeling**

- Biological consequences of climate change.
- Economic consequences of biological consequences.
- Direct economic consequences.
- Group interests vs. social values.
- Economic value vs. value of ecosystems, species, etc.

Week 10. **Policy Analysis I**

- Modeling the probable/possible impacts of alternative policy options.

- Coupling impact models with value dimensions. Problems of incommensurability: What we can predict may not be most relevant to our value concerns; what we most value may not be predictable. The need for negotiation between impact modelers and policy-makers.
- Policy-making regarding uncertain alternative futures.

Week 11. **Policy Analysis II**

- Judgment analysis: Systematic linkage of consequences of alternative policy options to dimensions that define group interests/values; integration of group interests by assigning relative weights to total impacts for each group on the basis of group size. Choice of the most "rational" policy. Criticisms of utilitarian ethics.
- Prediction of relatively certain impacts on indicator dimensions. The problem of extrapolation to other dimensions.
- Scenario approaches: Lumping groups and impacts in interconnected whole. The problem of intuition vs. analysis in value judgment. Possible vs. probable futures.
- Other methods: Science courts, education programs, science policy changes to accelerate scientific progress, unguided political process, etc.

Week 12. **Case Studies**

- The greenhouse effect: Prevention vs. preparation. Alternative sources of energy. Trade-offs between nuclear and fossil fuel commitments. Bioengineering and solar energy. Land and water resource management. Global agricultural planning.
- The ozone layer: Impacts on minorities; ecological vs. economic value.
- Nuclear and toxic waste management: short-term regional vs. long-term global solutions.
- Other cases of interest to class.

Week 13. **Communication Challenges**

- Interdisciplinary communication leading to collaborative research.
- Education: Problems of interdeparmental communication leading to interdisciplinary degree programs.
- Scientific education of public: Problem of popularization of science.
- Ethical education of scientists: Problem of “two cultures.”

Week 14. **Technological Solutions**

- Databases and information management.
- Scientific visualization for interdisciplinary and public communication.
- The information highway: New ways of making scientific information available to the public.

Week 15. **The Science and Ethics of Global Change**

- The interdependence between science and society. The institution of science as the information-producing analog of mitochondria.
- Gaia revisited: Planet management vs. blind adaptive control of the environment. A new stage of evolution?

1.2

Syllabus

Geosciences 489

Global Change*

1. Course Description

The course will address three different time frames of global change: (1)the interactions and coevolution of life and the global environment on all time scales–from approximately four billion years ago until the emergence of humans; (2)the ways that historical and contemporary societies have altered their environment, with particular attention to the significance of agriculture, industry, energy production and transportation, the use of land and water resources, overpopulation, alienation from nature, and poorly informed or nonexistent environmental policy and their implications for climate, health, and natural and artificial ecosystems; (3)the opportunities for planet management, with special attention to the varieties of models of global change and how they might be used (or misused)–in combination with impact models, analyses of alternative policy options, and informed value judgment–to favorably alter the probabilities associated with future global change.

2. Background and Motivation

Global change occurs on many different time scales. The hot solid material within the earth–called the mantle–“creeps” or circulates to move continental plates some tens of kilometers over millions of years–in ways that ultimately affect ocean circulation and climate. Yet even over years, the slow circulation of the mantle can

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*This syllabus was developed in 1994 by Dr. Larry Goldberg for the College of Geosciences and Maritime Studies and the Department Meteorology at Texas A & M University. The course is cross-listed in the Departments of Meteorology, Oceanography, Geography, and Geology/Geophysics and taught, at an upper division level, as the core course of the new college-wide global change curriculum.

cause earthquakes. Carbon dioxide levels in the atmosphere vary significantly over seasons, as photosynthesis varies with the available solar radiation. Yet its removal from the atmosphere by life and rain only begins the cycling of carbon through land, sea, sediment, and mantle. Over tens of thousands of years, outgassing from volcanoes and the mid-ocean rift return significant amounts of carbon dioxide to the atmosphere that had been removed from the surface by the subduction of sediment on the ocean floor into the mantle under continental shelves. Yet a single volcanic eruption can inject so much sulfate high into the air that the climate can be affected for years. Ice ages have come and gone about every hundred thousand years for the past few million years–most likely connected with changes in the earth's orbital relationship with the sun. Yet longer than two billion years ago, the evidence suggests that the earth was ice-free. Antarctica became glaciated more than 10 million years ago, although, in the present configuration of continents, the Arctic Sea wasn't covered year-round with ice until less than a million years ago. The sun itself changes over many time scales, from daily oscillations, to annual variation associated with the well-known 11- and 22-year solar magnetic or "sun-spot" cycles, to variation over centuries thought to be responsible for the recent "Little Ice Age," to the billions of years of stellar evolution associated with considerable changes in the earth's incoming solar radiation. The ice sheets and deep circulation of the oceans generally change significantly for climate over thousands of years, yet glacial surges may be responsible for rapid climate changes over decades. A change in the depth of the "mixed" layer at the top of the oceans can affect the climate over decades. Seasons come and go over months, while ocean eddies last months and transient atmospheric eddies that are responsible for our changing weather last only days to weeks. Yet anomalous couplings of the atmosphere and oceans–such as recent El Niño episodes that have caused the failure of fisheries, can last for years.

Most life on or near the earth's surface, of course, is tuned to the cycles of day and night. Species of plants or animals can evolve gradually over millions of years or, in special circumstances, rapidly over thousands of years. Bacteria that populated the earth almost four billion years ago evolve even more quickly due to their short life cycles and continual exchange of genes with other species. Over hundreds of millions of years, bacteria gradually changed the composition of the earth's atmosphere and oceans. Photosynthesizing bacteria, for example, first introduced oxygen into the atmosphere and oceans billions of years ago, creating a toxic environment for anaerobic bacteria and gradually setting the stage for the evolution of aerobic species. Plant life that arose only hundreds of millions of years ago accelerated this process, creating the oxygen-rich atmosphere we enjoy today and providing a mechanism for the efficient removal of carbon from the atmosphere.

Humans, by consuming fossil fuels that accumulated over millions of years in mere decades, are likely to cause a significant warming of the climate by the next century associated with an enhanced carbon dioxide greenhouse effect. Indeed, human society–through its energy consumption, use of land and water resources, agricultural practices, and industrial activities–is beginning to affect the composition, chemistry, and radiation levels–as well as the climate–of the planet on a global scale. The potential consequences of these polluting activities, although they are not known with certainty, are likely to have a great impact on soil and water resources, agriculture, ecosystems, and economies and to cause tragic extinctions of many species and health problems for many people. The ozone hole, radiation hazards, and toxic waste may increase the risks of cancer, air pollution can cause or aggravate respiratory, pulmonary, and cardiovascular diseases, and we are quite possibly causing the extinction of species at hundreds of times the natural rate of extinction–with little hope of replenishing the diversity of life by natural evolution. While mass extinctions–such as the great dinosaur extinction of 65 million years ago–have been known to destroy half or more of the earth's species, often apparently associated with major climate change, the constraints that humans place on the migration of species and their opportunities to find new niches may well preclude a "come back" from the devastation we are likely to inflict in coming decades to centuries.

One of the most important forms of global change has yet to occur. It is global change associated with informed and responsible global policy–with the international management of our planet. In order for civilization to have the opportunity to exercise some control at global and intergenerational scales, we will have to rely upon the predictions of global models to estimate the consequences of alternative policies. These models must represent the interactions among the surface subsystems of the planet: the lithosphere (land and sea floor), oceans, cryosphere (land and sea ice), biosphere (all life, including human society), and atmosphere. These subsystems exchange mass, energy, momentum, and, in the special case of the interactions between the environment and biosphere, information is also exchanged and stored in genes, institutions, social practices, and brains. The greatest challenge of the next century will likely be to gain enough understanding of our planet–and enough empathy with the predicament of life and humanity–to guide our future toward a sustainable global ecosystem with renewed evolutionary potential. This course is intended to place that challenge in the broad context of the global change that has already occurred over the past four billion years of life's coevolution with the composition, chemistry, and climate of its global environment.

An analogy between social cooperation and biological coevolution puts the social response to global change in an interesting light: There is evidence that different species of bacteria coevolved to create the nucleated (eukaryotic) cells that make up all plants, animals, and fungi. Perhaps the different areas of specialization within the geosciences will also "coevolve" to create a truly global science–a global science that will work together with other sectors of our society to sustain the biogeochemical cycles, biological diversity, agricultural productivity, ecological balance, and human health and well-being upon which the continued success of our own species undoubtedly depends. This course introduces the varieties of past and prospective global change in the hope of motivating student interest–whether as practitioners or global citizens–in the scientific study of global change.

3. Catalog Description

This course will review three broad categories of global change: (1)the origin and interactive evolution of the earth, atmosphere, oceans, cryosphere, and life; (2)the impact of human society on environmental chemistry, climate, and life; (3)the forms of global modeling and policy analysis that may help us to manage the planet.

4. Prerequisites

Junior or senior status.

5. Requirements and Texts

Students are required to complete two papers or projects. Papers are approximately 15 pages each. Projects may involve the development of a database, a global model or set of models, a policy analysis, or other approved analysis of some aspect of global change. Both papers and projects will be accepted a reasonable number of times for critical review in the course of their development. All topics for papers and projects will be chosen by students in consultation with the instructor–and will be subject to the instructor's approval. Attendance and class participation are expected.

Recommended texts include the following:

- *Biogeochemistry: An Analysis of Global Change*: William H. Schlesinger; Academic Press, 1991.
- *Changing the Face of the Earth*: I. G. Simmons; Basil Blackwell Inc., 1989.
- *The Coevolution of Climate and Life*: Stephen H. Schneider and Randi Londer; Sierra Club Books, 1984.
- *Early Life*: Lynn Margulis; Science Books International, Inc., 1982.
- *Earth and Cosmos*: Robert S. Kandel; Pergamon Press, 1980.
- *Earth in the Balance: Ecology and the Human Spirit*: Vice President Al Gore; Penguin Books, 1993.
- *Environmental Evolution*: Lynn Margulis and Lorraine Olendzenski, eds.; MIT Press, 1992.
- *A History of the Earth*: John J. W. Rogers; Cambridge University Press, 1993.
- *The Human Impact on the Natural Environment.* Fourth Edition: Andrew Goudie; MIT Press, 1994.

Other materials will be distributed during the course.

6. Course Outline

Part I. The Origins and Coevolution of Earth and Life.

Week 1. Theories of the origin of the sun and planets; the sun and its electromagnetic spectrum; the earth and its internal heat; the origin of the earth's core, mantle, lithosphere, oceans, and prebiotic atmosphere. The dynamic earth: plate tectonic motion, volcanic activity, sea floor spreading, and subduction. Theories of the origin of life. Explanations in terms of reproducing macromolecules, cell membranes, metabolic chemistry, panspermia, clay surface chemistry, etc.

Week 2. The evolution of bacteria and the composition of the early atmosphere and oceans: Early biogeochemical cycles; the roles of fermentation, photosynthesis, respiration, denitrification, etc. Photosynthesis and the emergence of free oxygen. Respiration and the carbon cycle. Carbon dioxide and climate. The first glaciation. The interactive evolution of the earth, atmosphere, oceans, cryosphere, and life. The endosymbiotic theory of cell evolution and the emergence of eukaryotic cells. Differentiation and aggregation: colonial organisms; multicellular plants, animals, and fungi. Life's invasion of continental interiors.

Week 3. Theories of speciation: Darwinian selection and random drift; punctuated equilibrium; self-organization combined with Darwinian selection. The coevolution of birds and plants; insects and plants. Parasitism, grazing, predation, symbiosis, and other forms of interspecific interaction and coevolution. Intraspecific cooperation: eusocial insect colonies. Ecology, evolutionary biology, and the relationship between organisms and their environment. The balance of cooperation and competition. Possible levels of selection. Global ecology: factual and speculative forms of interdependence among species; among ecosystems; between the biosphere and its environment.

Part II. Earth System Science

Week 4. Subsystems: the atmosphere, oceans, cryosphere, lithosphere, mantle, biosphere/society. Issues of time frame, variable frequency, causal significance, and system definition. The interdependence and interactive evolution of climate, environmental chemistry, and life. Scales of motion and the general circulations of the atmosphere and oceans. Defining climate over years, decades, centuries, millennia, etc.

Week 5. Transfers of energy and momentum within and among the climate subsystems. Radiative transfer: reflection, absorption, emission, and the electromagnetic spectrum. Radiative equilibrium as a special case of energy balance. Changes in heat storage and climate change: the hierarchical heat capacities of atmosphere, land, and oceans. The sun and climate change; the cryosphere and climate change. Transfers of energy and momentum across scales of motion. Sensible and latent heat transport. Albedo and snow and ice; albedo and clouds. Momentum transfer from winds to surface ocean currents. Temporal and spatial variation in depth of mixed layer. Exchanges between mixed layer and deep oceans. Transfers of mass: evaporation/transpiration-precipitation cycle; carbon cycle; other biogeochemical cycles. Atmospheric composition and climate. The biosphere and climate.

Week 6. Climate models: radiative, radiative-convective, energy-balance, general circulation, stochastic, and statistical. Coupling models of climate subsystems. The selection of a modeling strategy for a given purpose. Gaps in our knowledge: Clouds, turbulence, glacier dynamics, deep circulation of the oceans, feedbacks from vegetation changes, etc.

Part III. Anthropogenic Global Change

Week 7. The historical impact of humans on the environment: Population growth, migration, fire, hunting-gathering, agriculture, industry, energy production. Human impacts on animals, vegetation, soils, waters, geomorphology.

Week 8. Contemporary anthropogenic changes in environmental composition and chemistry: Aerosols; atmospheric carbon dioxide and other greenhouse gases; hydrofluorocarbons and the ozone hole; haze and smog; agricultural and industrial sources of water pollution; nuclear and toxic waste and hazards; deforestation, agricultural practices, cloud seeding, urbanization: their impacts on soil quality and the evaporation/transpiration-precipitation cycle; water resource depletion; desertification; resource depletion.

Week 9. Anthropogenic climate change: The enhanced greenhouse effect; aerosol coolings; the ozone hole; thermal pollution; vegetation and other land use changes and the associated changes in the evaporation/precipitation cycle, humidity, cloudiness, precipitation, and surface and cloud albedo. Sea level changes.

Week 10. Human impacts on the biosphere: Potential consequences of anthropogenic climate change and pollution for natural and artificial marine and terrestrial ecosystems. Agriculture, urbanization, hunting and fishing practices, outdoor entertainment and tourism and their consequences for biological diversity and ecological stability. Obstruction of species migration and movement of ecological zones with climate change.

Week 11. The social, economic, and cultural consequences of changes in global chemistry, climate, and ecology. The problems of developed and developing countries. Positive and negative effects of managed or partially managed ecosystems on environmental quality. Impacts, values, policies, and human ecology.

Part IV. Impact Modeling, Policy Analysis, and Planet Management

Week 12. Impact modeling and policy analysis: Modeling the biological consequences of environmental change, the economic consequences of biological consequences, the direct economic consequences of environmental change; issues of group interests vs. social values, economic value vs. value of ecosystems, species, etc. Modeling the probable/possible impacts of alternative policy options; problems of coupling impact models with value dimensions; policy-making regarding uncertain alternative futures.

Week 13. Case studies: (1) The enhanced greenhouse effect: Prevention vs. preparation. Alternative sources of energy. Trade-offs between nuclear and fossil fuel commitments. Bioengineering and solar energy. Land and water resource management. Global agricultural planning. (2) The ozone layer: Impacts on minorities; ecological vs. economic value. (3) Nuclear and toxic waste management: short-term regional vs. long-term global solutions. Other cases of interest to class.

Week 14. The prospects for planet management: The scientific problems of developing interdisciplinary models of complex systems, the cultural problems of adopting global values, communication problems and opportunities, political challenges. Continuing problems of uncertain knowledge. The need for flexibility. Trade-offs between natural and artificial life styles. Natural selection vs. genetic engineering. Other ethical and aesthetic issues.

Week 15. Broader world view considerations: Self-organization, evolution, and intelligence. The information highway and a new stage of evolution. Lessons for managing other solar system environments.

1.3

Philosophy 130.

Philosophy of Knowledge

Dr. Larry Goldberg
Assistant Professor of Philosophy

Fall 1990; Spring, Summer 1991
Lamar University

The Philosophy of Knowledge invites students to consider the basis for knowledge–or, at least, for well-justified theories, beliefs, or commitments–in a variety of disciplines and institutions. The course compares the methods of seeking and justifying theories, beliefs, values, or policies in such professional or social groups as the physical, biological, and social sciences; mathematics and philosophy; the literary, performing, and fine arts; religions east and west; and primitive and modern societies. This comparative analysis is approached in three ways: (1) inductively, as a search for similarities or differences among the actual disciplinary or social practices reviewed; (2) deductively, as an exploration of the applicability of certain theories of knowledge (such as those held by positivists, historicists, or pragmatists in the philosophy of science; empiricists or rationalists in traditional epistemology; and foundationalist or coherence schools of thought in contemporary epistemology) to the various disciplinary and social forms of knowledge; and (3) argumentatively, as a personal effort of students to critically evaluate the justifiability of various types of knowledge-claim.

1.4

INTRODUCTION TO PHILOSOPHY

Dr. Larry Goldberg
Assistant Professor of Philosophy
Spring 1991
Lamar University

As a discipline, philosophy embraces epistemology, ethics, aesthetics, metaphysics, and logic, as well as applications of one or more of these fundamental areas of inquiry to more specialized concerns, as in the philosophy of science, social and political philosophy, the philosophy of religion (or philosophical theology), bioethics and the philosophy of medicine, environmental ethics, philosophy and public policy, and the philosophy of mind (or philosophical psychology). Introductory courses commonly organize their sampling of philosophical literature around a unifying theme, such as the history of philosophy, philosophical issues, or applications of philosophy to contemporary issues of social significance. The present course is experimental in the sense that its organizing theme is not commonly employed. Although we do sample the philosophical literature related to fundamental issues, this provides the occasion for students to develop their own philosophical views which are continually presented and defended in class discussions as well as papers.

The topics for papers will be chosen by students with the guidance and approval of the instructor. These topics should relate to issues discussed in class, but students will be encouraged to orient their research and papers toward their personal interests, their majors, or their professional goals. This is not to say that papers will simply express student opinions. Each paper should: (1) clearly identify an issue; (2) review a representative range of views regarding that issue, with evidence of scholarship; (3) evaluate the adequacy of the justification for these various positions; (4) take a personal position regarding the issue; (5) defend that position with careful argument; (6) show an awareness of the limitations of one's own argument, such as any assumptions and conditions it may have presupposed or any limitations in the scope of its conclusion; and (7) indicate the social or personal significance of the defended position.

If the course succeeds, students will develop a number of important abilities: (1) the ability to read or listen to another thinker with respect and patience and understand what he or she believes; (2) the ability to analyze the justification and sense the motivation for the ideas of others; (3) the ability to critically evaluate the arguments of others; and (4) the ability to develop and defend positions and perspectives of one's own. Although student papers will be related to the issues addressed in assigned readings and discussed in class, students will not be forced to review in their papers the literature they have read for homework. It is philosophical ability that will be graded, not philosophical regurgitation. However, attendance will be taken daily and the instructor reserves the right to use attendance records as evidence of class involvement. Furthermore, class will be an ideal place to practice philosophical skills and involvement in class discussions will also contribute to grades. Class will also provide essential background on the topics treated in the text (Elliot Sober's book, *Core Questions in Philosophy*).

The topics covered in the text and class will include: (1) the logic of argumentation, including deductive, inductive, and abductive forms of reasoning; (2) the philosophy of religion (the text treats epistemological issues related to religious knowledge and metaphysical issues related to the existence of God; the class discussions will supplement the book's treatment and review some of the ethical issues associated with religious belief and practice); (3) the theory of knowledge (epistemology); class discussions will emphasize a comparison of scientific ways of knowing with the religious ways of knowing treated earlier in the course; (4) the philosophy of mind, with a focus on the "mind-body problem," i. e., the question of how mental experience and physiological processes are related to one another; (5) and ethics, with a focus on the writings of well-known philosophers who were associated with the major schools of ethical thought. Three ten-page papers will be required, including at least one paper on an ethical issue, one on an epistemological issue, and one on a metaphysical issue or an issue selected from the philosophy of religion or philosophy of mind. As indicated above, the specific topics of these papers will be selected by the student with the guidance and approval of the instructor. Papers must be typed and double-spaced (not triple-spaced) to leave room for comments. There will be no final exam. (The third paper will count as a final.) Meetings with the instructor will be encouraged and should provide an extra opportunity for students to clarify their ideas and get some coaching on their styles of thinking and writing. The best attitude to bring to class is an ethusiastic interest in all areas of knowledge, the courage to think independently, and the humility to subject one's own ideas to critical review.

1.5

EXPERIMENTAL STUDIES 423.

TOWARD A PARADIGM OF HOLISTIC RESEARCH

Instructor: Larry Goldberg Spring 1979
Department of Philosophy University of Colorado

The vision of holistic research has been around for decades. We have long recognized the importance of understanding the organization of biological, social or environmental systems. Unfortunately, the organization of complex open systems is very difficult to study. When we try to derive it from our analyses of a system's constituents, we may get lost in detail and never "put Humpty-dumpty together again." When we try to simulate the organization of the system's behavior more directly, we often over-simplify. And when interdisciplinary research is required, we have little experience with shaping the contributions of differnent disciplines into an unbiased and unconfusing whole. All of these obstacles to holistic understanding result in very uncertain assessments of biological, social, and environmental risks, to say nothing of a very uncertain understanding of our world. It may therefore be important to take the challenge of the above obstacles to holistic understanding seriously and work toward a "paradigm" of holistic research.

1.6

EXPERIMENTAL STUDIES 421.

THE MIND-BODY PROBLEM

Instructor: Larry Goldberg — Fall 1977
Department of Philosophy — University of Colorado

Is the human brain a computer-like mechanism which is provided with "programs" and "data" by the rest of the body and the environment? In what sense might human consciousness allow humans to be free in a way that "machines" could not be free? Questions such as the above will be considered from the point of view of the philosophy of mind, neurophysiology, computer simulation, the history and philosophy of science (Kuhn), systems science, and–most importantly–from the various points of view of students in the class.

Texts

Jerome A. Shaffer: **Philosophy of Mind**, Prentice Hall.

Thomas S. Kuhn: **The Structure of Scientific Revolutions. Enlarged Second Edition**, University of Chicago Press.

Ervin Laszlo: **Introduction to Systems Philosophy: Toward a New Paradigm of Contemporary Thought**, Harper Torchbook.

Format

Lecture on readings and related topics in the first half of each class; discussion in the second half.

Requirements

Two or three papers; class presentation optional.

Credit

This course is offered through the Experimental Studies Program and provides a 400-level credit on a pass-fail basis.

Prerequisites

Junior or Senior Status or instructor's consent.

Part 2

Selected Proposals

2.1

The Integration of Interactive Visualization, Electronic Communication, and Information Management: The Development of a Virtual Reality Tool for Environmental Modeling, Public Education, and Policy Analysis.

A Pilot Project. [*]

Communication, information, and visualization technologies are beginning to transform research and informal education in many areas of science. Scientists exchange ideas, publish in electronic journals, and find new colleagues with the help of e-mail. Powerful information management systems, often with graphical user interfaces, provide access over the Internet to many types of data and information from widely distributed sources. And scientific visualization, interactive when possible or rendered more slowly when the computational burden makes it necessary, provides feedback and ”virtual experiment” capabilities for many types of design and modeling and is becoming an important medium of interdisciplinary and public education. Yet as rapidly as these technologies have developed, it is only recently that the development of hybrid technologies has become feasible.

In one interesting application, a virtual laboratory, computer center, library, and conference center has been developed at the Weizmann Institute in Israel. Based on the “Multiple-user dimension, Object Oriented” (MOO) technology originally developed by Xerox’s Palo Alto Research Center for entertainment purposes, the “BioMOO” allows biological scientists to confer with one another, with the informality of discussions or the formality of a conference, in real time. Moreover, they are able to maintain virtual libraries and research centers to share their findings and research activities (such as modeling or simulated experiments) with other researchers. All of this can be enjoyed over the Internet through a telnet or Gopher connection. In the next generation of BioMOO, interactive visualization capabilities will be made available, at least under the bandwidth

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[*] Proposal to the Office of Vice President for Research and Associate Provost for Graduate Studies at Texas A & M University. Prepared by Dr. Larry Goldberg on behalf of the Visualization Programs at the College of Architecture.

constraints of the Internet. In another hybrid technology experiment, Texas A & M has joined many other campuses around the world in the integration of information management and low resolution visualization through its deployment of the XMOSAIC access system for information available over the Internet. In another technology experiment that controls real technology with virtual reality, high resolution scientific visualization has been made available remotely at virtual electron microscope sites by an application developed by several visualization programmers at the San Diego Supercomputer Center. It actually allows the remote operation, via a high bandwidth network, of an electron microscope from workstations running the virtual microscope program.

The next step in the integration of communication, information management, and scientific visualization technologies will involve the use of all three in a unified system, with applications for research, education, and policy-making. Although researchers within a field often have access to leading edge visualization technologies, researchers in different disciplines rarely have the opportunity to interact visually with each other's models. There is a special need for such user friendly interdisciplinary information transfer in many areas of science that model environmental change and its biological and social consequences. Moreover, collaborative relationships would be fostered if disciplines could develop their submodels in continual interaction with one another as well as with one another's models and findings. In policy analysis contexts, there is a need to communicate possible impacts to citizens or policy makers in ways that facilitate their definition of value dimensions which are sensitive to expert predictions, while scientists must be made aware of socially relevant value concerns in order to make predictions or simulations that are useful in policy making. This iterative process of coordinating impact prediction and value judgment could be facilitated, as could the process of developing interdisciplinary environmental models that couple the respective outputs and inputs of a hierarchy of physical and chemical, biological, and social and economic models, through an Environmental MOO that integrates conferencing capabilities with locally rendered high resolution scientific visualization in connection with remote data sets and models maintained by the collaborating groups.

The proposed project would be pursued in three stages: (1) The organization of a team, including faculty members affiliated with the Visualization Programs and Laboratory of the College of Architecture and, tentatively, the Institute for Scientific Computation, affiliated with the Colleges of Science and Engineering, and the Center for Biotechnology Policy and Ethics of the Institute for Biosciences and Technology, affiliated with the College of Liberal Arts and the College of Agriculture and Life Sciences–as well as information management, modeling, and policy-making groups to be selected by the three founding groups. The former founding groups would be responsible, respectively, for developing the visualization, distributed computing and information management, and policy analysis components of a project proposal to a federal funding agency. We are seeking support for this phase from the Office of the Vice President for Research only for the salary of the project coordinator, Dr. Larry Goldberg, who will facilitate the collaboration of all of the participating groups, and progressively integrate their contributions and ideas into a final proposal. (2) The systematic study of alternative visualization, information management and distribution, and policy analysis methods in a one-year project, the results of which should indicate fruitful strategies for the development of an integrated environmental science and policy making "MOO" and visualization system that is technologically feasible and cognitively adequate in its presentation of information to all expert and decision-making groups involved in interdisciplinary model development and the utilization of coupled models for environmental planning and management. (3) The development of an integrated virtual reality system for interdisciplinary communication, collaborative model development, public education, and policy analysis, on contract with a policy-making or environmental management agency.

2.2

A PROPOSAL FOR ENHANCING RESEARCH AND EDUCATION IN THE COMPUTATIONAL SCIENCES AT TEXAS A&M UNIVERSITY [*]

August 1993

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[*] First draft of proposal to private foundation prepared by Dr. Larry Goldberg for the Institute for Scientific Computation, Texas A & M University, summer 1993. Appendices omitted for convenience.

1. Executive Summary

The explosive growth of computer technology has revolutionized the character of many areas of science. The use of high speed computers to approximate the solutions of systems of differential equations has enabled scientists to develop mathematical models of systems of much greater complexity than ever before. The methods of approximation and algorithms for implementing these methods on particular computer architectures are developed by applied mathematicians and computer scientists. Mathematical modeling has become so dependent on computer technology and the contributions of mathematicians and computer scientists that it has become a new field, *computational science.* Quite often computational models treat systems of such complexity that several disciplines studying different aspects of the same system must contribute to these models. Because computational science is inherently interdisciplinary, it has made interdisciplinary education and interdepartmental degree programs important at a growing number of research universities.

Texas A&M University (TAMU) has responded to research and education needs in computational science in two significant ways. First, the University formed a new institute, the *Institute for Scientific Computation* (ISC), whose mission is to enhance computational research and education on campus. Toward this end, the ISC has begun to create an infrastructure of distributed file serving, parallel distributed processing, and software tools for compression, visualization and other modeling needs. The ISC also has facilitated the formation of some twenty interdisciplinary research teams–called "clusters"–that focus on different areas of computational science. Second, TAMU has instituted new degree programs at the B.S., M.S. and Ph.D. levels in applied and computational mathematics. More researchers and students must be attracted to the computational sciences, however, for the field to flourish at TAMU. An assessment of research and education strengths on campus indicates the need to stimulate new research and the development of new degree programs in the following areas:

- scientific visualization
- computational science/engineering/mathematics

- education (educational technology)
- computational biology/chemistry
- materials science
- molecular biology/genome mapping

In order to enhance the intellectual resources of the university in the above areas, the creation of endowed chairs in each of these areas is proposed below.

2. Introduction

In the past two decades, science has been transformed by the explosive growth of computer technology. Computational modeling, in particular the development of mathematical models of complex systems, now plays a key role in contemporary science. As computer speeds have increased steadily, it has become possible to develop models of ever greater size and complexity. It is now possible to approximate the solutions of large–and often nonlinear–systems of differential equations with the help of numerical techniques developed by applied mathematicians and computer scientists. Computer "experiments" help researchers explain and predict the behavior of complex systems by exploring the response of numerical models to a variety of conditions and assumptions.

The growth of computational science has transformed modern science in several distinct ways:

- *Technology.* Making appropriate technology available to researchers is necessary for successful computational science. Because large quantities of data often must be stored and transmitted, data compression tools are becoming increasingly important. As more complex problems are studied, researchers are increasingly dependent on scientific visualization for the interpretation of model outputs and the examination of empirical data. Scientific visualization also plays an important role in the communication of research findings and results to scientific and policy-making communities and the public. As problems become larger still, massively parallel computing (whether in the form of parallel computers or parallel distributed computing that integrates the resources of many workstations and computers) will be needed to make computation efficient and economical.

- *Interdisciplinary Collaboration.* Separate disciplines often study different aspects of the same physical system–for example, different processes, components, subsystems, scales of motion, or levels of structure or organization. Historically, this *divide-and-conquer* problem-solving strategy has encouraged specialization. However, when scientific problems require answers that cross disciplinary boundaries, interdisciplinary collaboration is essential. One of the great advantages of computational science is that it provides a mathematical framework that can be shared by any number of disciplines in the development of interdisciplinary models of complex systems. Computational science undoubtedly has accelerated interdisciplinary forms of scientific progress.

- *Applied mathematics and computer science.* Research is needed to develop efficient and accurate mathematical methods for numerically approximating the solutions of systems of differential equations. Research is also needed to implement these mathematical methods on particular computer architectures. Thus computational scientists are quite dependent upon the expertise of applied mathematicians and computer scientists for numerical methods, software tools, compilers, operating systems, etc. As parallel computing becomes more prevalent, computational scientists will find it important to collaborate more directly with applied mathematicians and computer scientists to coordinate the development of mathematical models and the numerical methods and algorithms employed.

- *Scientific visualization.* Extremely large data sets are nearly incomprehensible when presented in purely numerical form. For this reason, it has become vital in many areas of science to visualize empirical data sets as well as the outputs of mathematical and computational models. Data compression contributes to visualization by allowing researchers to overcome limitations in the bandwidth of networks, computer speeds, memory and storage, and the resolution of display devices. Scientific visualization represents a new area of research that contributes to the understanding of the behavior of models and the communication of the results of computational science within and beyond the scientific community.

- *Education.* The strong connections that exist among the disciplines involved in computational science and technology offer an exciting challenge for the development of interdisciplinary curricula and team research experiences for students. Educators have a special role to play in evaluating the impacts of visualization and related technologies on the learning process–as well as the cognitive demands of interdisciplinary education. Research in cognitive science and education is needed to explore the potential value of educational technologies and other innovative teaching methods across a spectrum of educational levels–from K-12 through postdoctoral training.

Computational science enables researchers to study complex nonlinear systems and foster synergistic relationships between science and technology. This new field is already beginning to transform the organization of research and education within universities. In order to further this process, it is essential for Texas A&M to provide an environment conducive to the collaboration of the science, mathematics, and engineering disciplines involved in computational science. As "big science" becomes more and more prevalent, faculty and students will need to participate in research teams that are interdisciplinary and will need to have a variety of computing, network, visualization and software tools available for their research. TAMU is committed to the development of the needed interdepartmental and technological infrastructure for computational science to flourish on the campus.

This proposal assesses the impact of recent developments at Texas A&M University on the creation of an environment conducive to leading-edge research and education in computational science. It identifies several areas which need special emphasis and proposes a plan that can help the university to achieve its goals and become a leader in computational science research and education.

3. Computational Science at Texas A&M University

Texas A&M University (TAMU) is the second largest university in Texas and third largest in the nation; it ranks sixth in funding for research and engineering projects. Although there is no formal degree in computational science, Texas A&M offers many degrees permitting specialization in areas of computational science, primarily in its Colleges of Science, Geosciences, and Engineering. Research in computational science is extensive and growing in all colleges and a technological infrastructure is rapidly developing for distributed parallel processing capability, visualization, and computational modeling software tools. As the scope of interdisciplinary research activity involving computational science has increased, Texas A&M has developed a number of collaborative projects with other universities, research institutions and government laboratories. Recent developments in education, research, technology development, and collaborative projects are discussed in turn.

Education. It has been recognized that mathematics and computer science provide the methodological foundations for all areas of computational science and that it is essential to provide opportunities for science, engineering, and mathematics graduate students in the areas of numerical analysis, computer science and approximation theory. New courses have been developed in computational linear algebra and finite elements, a new M.S. program with concentrations in computational and applied mathematics has been created, and a new Ph.D. program in computational and applied mathematics has been proposed. Qualifying exams are now offered at the Masters and Ph.D. level in numerical analysis.[1] The computer science department also has a strong computational orientation and offers courses in computer architecture, computational geometry, parallel geometric computing, parallel algorithm design and analysis, parallel/distributed algorithms and complexity theory. Although a formal degree program in computational

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[1] For an outline of the new and proposed degree programs in computational and applied mathematics, see Appendix 5.

science does not yet exist, graduate students with interests in this area have many opportunities to gain expertise. New degree programs in Visualization Sciences (College of Architecture) and Educational Technology (College of Education) have helped to establish Texas A&M as a leader in visualization and interactive multimedia technology as well as in more established areas of computational science, mathematics, and engineering.

Research. Many departments and colleges at Texas A&M University have distinguished themselves in numerous areas of computational science and engineering.

- The Departments of Aerospace, Chemical, Petroleum, and Nuclear Engineering are well-known for their respective work in computational mechanics and fluid dynamics, multiphase flow in porous media, and neutron transport modeling.
- The Department of Mathematics has made substantial contributions to the methodology of computational science through its research in numerical methods, approximation theory, and inverse problems.
- The Computer Science Department is well-known for its research in artificial intelligence, parallel architecture and algorithms, and complexity theory.
- The Department of Physics has distinguished itself in the areas of high energy, particle, and condensed matter physics.
- The Biology Department is well-established in the areas of molecular and cell biology.
- The Chemistry Department is one of the most prestigious in the country and currently is strongly committed to establishing a molecular visualization laboratory with highly computational foundations in molecular dynamics.
- The College of Geosciences houses the Departments of Meteorology, Oceanography and Geophysics as well as the Climate System Research Program–which have strong computational interests, respectively, in atmospheric, oceanic, geophysical, and climate modeling.
- The College of Architecture has developed a Visualization Sciences Program with a strong focus on issues of human interface design.
- The College of Education has a program in Educational Technology with a strong focus on cognitive evaluation of interactive technologies.

- The Colleges of Medicine, Veterinary Medicine, and Agriculture are all involved in the leading edge of medical imaging technologies and biochemical modeling.

The presence of so many strong research programs offers unique opportunities for computational science.

Technology. Equipment currently available over the campus network includes a 2.2 Gfl 28 node Intel-Paragon, a 64 node N-Cube, a 2048 node massively parallel MASSPAR, a Cray YMP-2, numerous SGI and Sun workstations, along with access terminals distributed throughout campus. Additional facilities include on-line video production, editing and projection systems. Through the coordinating activities of the recently established Institute for Scientific Computation (ISC), Texas A&M has organized a number of autonomous computational clusters that are tied together through shared use of the software tools and distributed file system provided by ISC. Users at a Unix workstation or X-Windows terminal see a standard Network File System (NFS) interface and can take advantage of distributed data storage as well as the compression, visualization, and software tools provided by ISC. Computation can be optimized on remote machines through the use of Network Queuing System (NQS) and Parallel Virtual Machine (PVM) software. The comprehensive package of services provided on campus, largely due to the coordinating activities of ISC, promising to make Texas A&M a leader in computational science.[2]

Collaboration. Although the ISC has been established only one year, it has helped the university become involved in a number of collaborative projects with leading research and education institutions here and abroad. Two representative projects involve groundwater contaminant transport and the application of splines and wavelets to problems of data compression and visualization. The groundwater project is supported by the Department of Energy through its High Performance Computing and

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[2] For a list of the technology available to research teams associated with the ISC, see Appendix 3.

Communications (HPCC) Program. Members of the Partnership in Computational Science (PICS) consortium include the Departments of Mathematics, Computer Science, Aerospace and Chemical Engineering at Texas A&M. Outside members include Rice University, the University of South Carolina, and the University of New York at Stony Brook; as well as the Oak Ridge, Sandia, and Brookhaven National Laboratories. The wavelet project, funded by Texas Instruments, EDS, General Motors and General Dynamics, involves the collaboration of the ISC with the Center for Approximation Theory at the Department of Mathematics.

Recognizing unique regional strengths, Texas A&M is holding discussions with the University of Texas at Austin, the University of Houston, Rice University, HARC and other Texas institutions regarding the creation of a regional supercomputer center.[3] The future expansion of Texas A&M's computational infrastructure will be amplified through the exchange of information resources, software tools, and computational services with other institutions. To date, there exist collaborative relationships with Cornell, Purdue, Rice, and the University of Texas at Austin in this country. International agreements exist with INRIA-France, St. Petersburg, the Moscow State Universities, Academia Sinica, Sofia University, the University of Bergen, the Russian Academy of Sciences and the Bulgarian Academy of Sciences.

4. The ISC *Cluster Development Plan*

Texas A&M University has made a commitment to computational research and education on its campus. One significant development has been the formation of the Institute for Scientific Computation (ISC). Directed by Dr. Richard Ewing, the ISC was founded in 1992 with the mandate to facilitate and coordinate the growth of computational science at Texas A&M. Dr. Ewing directed a similar

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[3] For an outline of plans for cooperation among regional universities in the development of a supercomputer center, see Appendix 4.

institute at the University of Wyoming, where he first developed the model of sharing computer and software resources over the campus network and formed interdisciplinary teams, called "clusters," for computational modeling, mathematics, and software development projects. Under the leadership of Dr. Michael Pilant, Associate Professor of Mathematics and Associate Director of the ISC, Texas A&M researchers have been exchanging information and sharing resources in the area of computational science and mathematics for years. It was not until the formation of the ISC in 1992, however, that large-scale computing efforts on campus began to be consolidated and integrated in a more formal way.[4]

The ISC contributes to computational science on campus in the following areas:

- *Technology*: hardware acquisition, development, and distribution.
- *Software*: development of modeling, compression and visualization software.
- *Research Infrastructure*: development of new interdisciplinary programs.
- *Education*: curriculum development and training.
- *Funding*: extramural fund-raising and interdisciplinary proposals.
- *Outreach*: external communication and collaboration with other institutions.

Twelve computational science clusters have been formed to date and six others are expected to form soon. These involve approximately 75 faculty, 30 postdoctoral researchers, 13 staff members, and 80 graduate students. The established, and soon to be established clusters, are as follows:

- aerospace engineering
- approximation theory/wavelet analysis
- architecture/human interface design
- biology
- central cluster

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[4] For a list of current associates of the ISC, see Appendix 1. For a list of current research clusters, see Appendix 2.

- chemistry
- computer science
- geosciences
- Institute for BioSciences and Technology (IBT)
- mathematics
- mechanical engineering
- petroleum/chemical engineering
- physics
- statistics

The clusters provide an organized context for interdisciplinary research through departmental, interdepartmental, college-wide and intercollegiate programs or initiatives. Common research interests as well as shared interest in hardware and software resources and mathematical and modeling methods are creating a fertile environment for collaboration within and between the clusters. The clusters are also are vehicles for the acquisition, development, maintenance, and distribution of hardware and software technology. They aid in the development of courses, curricula, internships, and workshops that better meet the needs of departments in methodological and mathematical training. Finally, the clusters facilitate interdisciplinary grant writing efforts; and, through the central cluster, initiate collaborative relationships with other research, education, government, and industrial institutions and laboratories.

The ISC has negotiated the donation of equipment, or the purchase of equipment at significantly reduced cost, with such hardware vendors as IBM, Silicon Graphics, Intel, and Sun. One of the principles of the cluster organization concept promoted by the ISC is that the hardware and software tools available to one cluster should be made available to all. This arrangement, combined with the distributed file serving currently available and the parallel distributed processing that will be available soon, have made the computational environment of the campus unusual in the services it can provide.

5. Goals and Objectives

It is essential to the mission of Texas A&M University that it provide a exceptional environment for leading-edge research and education. In order to do so in the area of computational science, the university must expand its faculty, research activities, technological infrastructure, educational curricula, and collaboration with other universities and institutions. We propose the following goals and specific objectives for Texas A&M's computational science enhancement strategy.

5.1. Goals

(1) Provide intellectual resources on campus for the formation of interdisciplinary computational science research teams. Expand the course offerings of science, mathematics, computer science, and engineering departments in areas of computational science.

(2) Provide the expertise on campus in applied mathematics, computer science, mathematical modeling, and visualization necessary to guide the development of a technological infrastructure of parallel distributed processing, modeling, compression, and visualization tools. Provide technical support that will further productivity and training in computational science.

(3) Contribute to the leadership of the scientific community in Texas in ways that will facilitate and justify the development of large-scale computational facilities, such as a regional supercomputer center, that can serve the region's growing activity in computational science and engineering.

5.2. Objectives

The objectives of Texas A&M in the proposed enhancement of computational science on campus are the following:

(1) It is essential that the campus work toward an interdisciplinary degree program in computational science and engineering. Much of the funding in the area of computational science depends upon the existence of such a program. Moreover, it is essential to provide methodological background in mathematics and computer science together with the opportunity to apply this methodology to particular areas of science or engineering. Existing programs in mathematics and computer science do not provide extensive background in applications, while courses offered through science and engineering departments do not allow sufficient specialization in computational methods. The proposed computational science program would offer training in numerical methods, the theory of approximation, parallel architecture, parallel/distributed algorithm development, etc., to be followed by specialization in an area of computational science or engineering.

(2) There is a need to strengthen critical areas of research and education in computational science methodology and applications. It is especially important to consider the strategic hiring of leaders in the various interdisciplinary areas of that could attract new faculty to fill the gaps in campus expertise. These distinguished faculty would then attract students and postdoctoral researchers with computational science interests, direct new departmental and interdisciplinary programs, bring significant funding to the school, and represent the university in interactions and negotiations with other institutions in areas of computational science. Six proposed endowed chairs have been identified that could bring to the university a more representative expertise and the reputation and initiative needed to fulfill the goals of the university in the computational sciences.

(3) Encourage the development of compression, visualization, statistical, and modeling software tools, information management systems, graphical user interfaces, and massively parallel distributed processing resources which would then be available to campus researchers over the campus network.

(4) Provide assistance for the coordination of interdisciplinary grant-writing efforts in computational science.

(5) Provide a context for the organization of interdisciplinary symposia and workshops in computational science.

(6) Establish relationships with other universities and institutions in Texas that will allow the sharing of expertise and technological resources in areas of computational science.

6. Grand Challenge Research and Education: An Action Plan

The High Performance Computing and Communications (HPCC) initiative has identified some twenty "grand challenges." These are listed here by area of research:

- geosciences
  - weather and climate prediction; global change
  - computational ocean sciences

- physics
  - astronomy
  - quantum chromodynamics
  - turbulence
  - superconductivity
  - nuclear fusion

- engineering
    - materials science
    - semiconductor design
    - transportation
    - vehicle signature
    - vehicle dynamics
    - combustion systems
    - oil and gas recovery
    - undersea surveillance for anti-submarine warfare
- biological sciences
    - human genome
    - structural biology
    - drug design
- artificial intelligence
    - speech
    - vision

With the possible exception of several research areas of primarily military interest, all of the grand challenges listed above are research priorities at Texas A&M University. For example, the College of Geosciences and Maritime Studies is involved in computational global and ocean modeling. The affiliated Institute for BioSciences and Technology is involved in the Human Genome Program and drug design research. The Departments of Chemistry and Biology are involved in computational molecular dynamics research. Materials science is of interest to the Departments of Physics, Chemistry, Mechanical, Aerospace, and Chemical Engineering and the affiliated Texas Laser Laboratory (at HARC); and the areas of artificial intelligence listed are of interest to the Department of Computer Science. Nuclear Fusion is studied in both the Physics and Nuclear Engineering Department. Oil and gas recovery are addressed by computational modeling at the departments of petroleum and chemical engineering as well as in research at ISC. All of the above science areas as well as aerospace and chemical engineering and the IBT are represented as ISC clusters.[5]

While the University has a broad research base that is quite responsive to the HPCC grand challenges, the research conducted and educational programs developed to date have been primarily departmental in orientation. Despite the enthusiasm for the ISC cluster concept, the growth "big science" at TAMU will require more faculty leadership to bring together the disciplines, technologies, students, training, and funding needed for success. The creation of a number of endowed chairs in critical areas of computational science would help to provide the needed leadership. The University also needs to develop several degree programs that reflect the interdisciplinary structure of the computational sciences. TAMU's new and proposed degree programs in applied and computational mathematics have been mentioned above.[6] Yet broader interdepartmental degree programs are needed that combine training in computational mathematics and computer science methodology with more specialized training in science or engineering applications. The creation of six endowed chairs and a strategy for working towards interdepartmental M.S. and Ph.D. programs in computational science are proposed below.

6.1. Six Endowed Chairs in Critical Areas of Computational Science

Six chairs have been identified strategically for the key roles they will play in the enhancement of computational science research, education, technological development, and outreach. Their areas of specialization are listed below and respectively motivated in the following discussion.[7]

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[5] See Appendix 2 for a list of current ISC research clusters.

[6] These are outlined in Appendix 5.

[7] The significance of the proposed chairs in the distribution and interconnections of expertise on campus is represented in Figure 1, Appendix 6.

- scientific visualization
- computational science/engineering/mathematics
- education (educational technology)
- computational biology/chemistry
- materials science
- molecular biology/genome mapping

An endowed chair in **scientific visualization** will enhance the expertise represented in the core cluster. The departments of mathematics (with a focus on numerical methods, parameter estimation, inverse problems), statistics, and computer science (with a focus on numerical algorithms, pattern recognition, and parallel architecture) are involved in funded research to develop approximation, compression, and visualization software. This software will be made available to researchers over the campus network. This work has been done in collaboration with the aerospace engineering cluster, which includes expertise in finite difference methods and wavelet analysis. Although the software tools under development are likely to make original contributions to the field of scientific visualization, they represent only a few of the many areas of research and many possible distributed visualization strategies. If a leading expert in scientific visualization were located at Texas A&M University, he or she would facilitate research activity in a variety of visualization methods, make these methods better known in computational science departments on campus and at neighboring universities, and provide leadership in the core cluster. With expertise in applied mathematics, computer science, and visualization, the core cluster would provide a context for faculty and graduate students to participate in leading-edge research in the broadly defined fields of computational mathematics and scientific computing and would be in a position to facilitate the development of interdisciplinary courses and degree programs that could keep pace with the growing importance of computational mathematics in every field of computational science.

An endowed chair in **computational science/engineering/mathematics** would serve to bridge the gap between the computational physical modeling activities in the Colleges of Science and Engineering and also to connect these activities more directly with the computational mathematics methodologies in the core cluster. Research on the Texas A&M campus–as at most research universities–is generally conducted very independently in the respective schools of science and engineering. Yet the methods of mathematical and computational modeling are shared by scientific and engineering disciplines. This shared methodology will undoubtedly lead to more collaboration in the future, especially as industrial grants and joint ventures with industry become more important in the support of university research. ISC is in a unique position to facilitate collaboration between scientific and engineering researchers, since it is jointly affiliated with the Colleges of Science and Engineering. If an endowed chair were created for a distinguished professor with a joint appointment in physical science and engineering departments, he or she would be in a good position to attract other faculty and graduate students to work at the interface of computational science and engineering. As an expert in computational mathematics methodology, the proposed chair would also serve to connect the computational mathematics core with the computational science and engineering research clusters and provide the interdepartmental leadership needed to create interdisciplinary degree programs in computational science.

An endowed chair in **computational biology** would help unify the computational science research and education activities of a number of TAMU departments, colleges, and institutes. These include the Departments of Biology and Chemistry in the College of Science; the Colleges of Medicine, Agriculture, and Veterinary Medicine; and the Institute for BioSciences and Technology. Computational biology embraces both the computational processing of raw data from the various forms of imaging–such as x-ray crystallography, NMR, and MRI–and the development of mathematical models of complex biological systems (such as ecosystems) and biochemical systems (as in molecular dynamical models of protein structure, behavior, and interactions). There is a growing interest in computational biology on campus and a distinguished professor in the field will help the biology and chemistry departments and the medical/life science colleges exchange methods, interact with the computational mathematical core, and collaborate on particular problems.

An endowed chair in **education**, with a emphasis on the role of computation and visualization in education, would help to build a stronger connection between the existing Educational Technology Program, the psychological and cognitive sciences, and scientific visualization. A distinguished professor in education would be able to bring cognitive science to bear on problems of evaluating the effectiveness of visualization strategies and would be able to provide leadership in transferring visualization technologies developed on campus to public schools and, indeed, to Texas A&M's science and science education courses.

An endowed chair in **materials science** would serve to create a bridge between the College of Engineering and the Departments of Physics and Chemistry in the College of Science. Condensed matter physics, for example, is one of the research priorities of the Department of Physics, which has strong connections with the Texas Laser Laboratory at HARC. The Department of Mechanical Engineering is well-known for its work in materials science, the Department of Aerospace Engineering has expertise in composite materials, and the Department of Chemical Engineering is known for its work in polymers and biochemical engineering. A distinguished professor with a computational orientation would foster strong ties with the Institute for Scientific Computation and methodological connections between science and engineering research.

An endowed chair in **molecular biology/genome mapping** would create bridges among the Institute for BioSciences and Technology (IBT), the Departments of Chemistry and Biology, and the School of Agriculture–which houses the university's biochemistry department and has strong interests in genome mapping and the development of genetic resource databases. There are many issues of three dimensional pattern recognition, visualization, and information management–as well as molecular modeling–that have a computational focus.

If it were possible to create and fill the above six endowed chairs, and then augment them with supporting faculty appointments, Texas A&M would be in a position to become a leader in the rapidly growing field of computational science. New interdisciplinary degree programs would emerge from their activities to better reflect the interdisciplinary nature of emerging areas of computational science. The stature of the university would be enhanced and it would find itself in a better position to form collaborative relationships with neighboring universities and research institutions for large-scale research projects and cooperative technology development.

6.2 Toward Degree Programs in the Computational Sciences

The key to helpful degree programs in computational science is their ability to provide integrated training in mathematical and computer science methodology and science and engineering applications. B.S., M.S., and Ph.D. programs have already been instituted or proposed in applied and computational mathematics.[8] Yet graduates of these programs will not have sufficient opportunity to specialize in particular areas of computational modeling–whether in a science or engineering discipline. On the other hand, most science and engineering departments offer opportunities for dissertation research in computational areas, but most often do not provide team research opportunities or methodological training. A solution would be the formation of degree programs, say at the M.S. and Ph.D. levels, that would offer the same courses available in computational mathematics degree programs but an additional opportunity to take courses in science or engineering application areas and participate in team research guided by a science or engineering department of choice. Steps could be taken in this direction through the co-listing of many courses

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[8] See Appendix 5.

in computational math, science, or engineering in several departments. The opportunity for student interns to participate in team research situations coordinated by the Institute for Scientific Computation also would pave the way toward a more formal degree program. Most importantly, however, professors holding the endowed chairs proposed above will have the influence and motivation work together with the relevant departments to negotiate interdepartmental education and research opportunities for their students and colleagues.

7. Conclusion

We conclude that computational science is more than a new area of science or simply bigger science – it is qualitatively different from earlier science. It requires interdisciplinary collaboration among the disciplines that study different aspects of the same system. It requires collaboration among mathematicians, computer scientists, scientists, and engineers. It requires extensive technological support–more than most research groups can afford for their exclusive use. It requires a radically new kind of interdisciplinary training. And scientists and students alike can benefit from visualization of complex phenomena. We have attempted to develop a campus-wide initiative at Texas A&M University to support these developments. The creation of the proposed endowments would greatly accelerate our progress in this direction.

8. Appendices

2.3

An Interdisciplinary Approach to the Development and Evaluation of an Introductory Science Curriculum for Non-science Majors at the University of California, San Diego [*]

Background and Problem

The dismal level of science literacy in this country and our society's shortage of mathematicians, scientists, and engineers are well known. These problems have been addressed at the University of California, San Diego (UCSD) by a number of introductory science courses offered to non-science majors. These courses are taught by the University's best science faculty and are intended to provide an exciting opportunity forstudents to gain an appreciation of the intellectual challenges, research methods and styles, fascinating results, interdisciplinary significance, and social implications of the sciences. It is hoped that some of the students who take these courses will go on to major in science, while others will be inspired to take a lifelong interest in science essential to responsible participation in our technological world.

Too often, however, the large classes characteristic of a research university (100 to 400 students per class) and great differences in student preparation make it difficult for even the best teachers to adequately address the cognitive difficulties of many students. Cognitive difficulties often are compounded by fear of mathematical, scientific, and technological information. Cognitive and motivational problems often are associated, for example, with the following areas of deficiency in background,

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[*] The following pages represent my first draft, prepared in the spring of 1992 in my capacity as coordinator of a number interdepartmental projects at the University of California, San Diego (UCSD) and the San Diego Supercomputer Center, of three sections of an educational technology and curriculum development grant proposal that was eventually submitted to NSF by UCSD. The final version integrated most of this material, but my draft should not be taken to represent the views or plans of the faculty members that comprised our team.

ability, and confidence:

- algebra, geometry, trigonometry, statistics, graphical representation;
- laboratory or field experience;
- visualization of unfamiliar scales, objects, and mechanisms;
- understanding of scientific method and critical thinking ability;
- analysis of complex interdependent phenomena;
- background knowledge in relevant disciplines;
- appreciation of the social significance of science;
- library research skills and comprehension of technical literature.

In response to the national crisis in science education dramatized by the prevalence of student problems such as the above, a new initiative has been exploring ways of harnessing computing, information, and communications technologies to facilitate more involvement in the learning process and wider distribution of educational materials. Toward this end, a variety of institutions and projects have been funded by such federal agencies as NSF, DARPA, and DoEd. UCSD's and SDSU's involvement with the Community Learning and Information Network (CLIN), for example, promises to create a bridge between the High Performance Computing and Communications (HPCC) Program and educational commitments such as the President's AMERICA 2000 education strategy. A related expression of the educational technology initiative is the Metacenter concept whereby the country's supercomputer centers would provide distributed computing and information resources not only to the research and industrial community, but also to educational institutions. Through the use of the emerging capabilities of the National Research and Education Network (NREN), the hope is to transparently provide functional resources to all levels of user sophistication. Broadly conceived, there is a movement emerging dedicated to distributed, interactive, and multimedia forms of educational opportunity.

In the hope of charting territory at the cutting edge of the educational technology initiative, the proposed project will develop an unprecedented threefold technological response to student problems such as those outlined above for use and evaluation in six introductory science courses for non-majors offered at UCSD:

- hypermedia packages to support the syllabus of each course;
- communications connections for E-mail, library searches, etc.;
- an on-line multimedia library/information management system that provides basic skill and interdisciplinary enrichment resources for all introductory science courses.

The impact of this educational technology on basic skills, attitudes toward science and the science education experience, and achievement in the course will be evaluated. To the extent that the findings are favorable, the technological products and on-line library and services developed would become integral to the introductory science curriculum at UCSD and would be distributed to other universities and colleges in the hope of contributing to introductory science education nationwide.

Goals

Overcome barriers to science literacy by:

a) Enhancing the contribution of science courses for non-majors to science literacy.

b) Helping as many non-science majors as possible overcome deficiencies in scientific and mathematical background and phobias, motivational problems, and cognitive difficulties that obstruct their involvement and achievement in science.

c) Introducing non-science students to the use and role of computer, information, and communication technologies in modern science.

d) Producing hypermedia packages that supplement or contribute to the science curriculum for non-majors.

e) Facilitating intellectual communication among students and between students and faculty by providing E-mail boxes and communications service, for use by non-science majors.

f) Training tomorrow's K-6 teachers in the excitement of science, so that they can multiply the effect by carrying the attitudes and materials to their own students.

2. Create a resource center to:

   a) Develop an on-line information service that distributes digitized images, video, graphics, and data, as well as integrated hypermedia modules and packages, throughout campus for use by faculty and students, with particular emphasis on the needs of non-science majors.

   Specifically, we will develop an on-line information service that provides access, through distributed file-serving commanded by an information management system with a standard user interface, to multimedia materials and hypermedia modules and packages related to a number of science courses offered at the UCSD campus to non-majors.

   b) Develop an on-line multimedia information service that can supplement, through built-in searching tools, stand-alone hypermedia packages used by non-major science students.

3. Do research on:

   a) What works to motivate non-science majors to learn science.

   b) What works to increase comprehension and retention of scientific material for non-science majors.

4. Evaluate by:

   a) Studying the impact of hypermedia materials and information and communication services on student motivation, attitude toward science, and achievement in science courses for non-majors.

   b) Studying the impact of hypermedia materials and information and communication services on the teaching style and methods of students in the UCSD Teacher Education Program, who will become elementary school teachers in California.

5. Disseminate our knowledge by:

   a) Instructing high school and university educators in the use and development of hypermedia, information, and communication technologies through workshops and training programs.

   b) Negotiating relationships with other campuses to exchange information services over national networks.

   c) Seeking to contribute to science literacy and science education on a national scale, through distribution of materials, services, and knowledge gained from the research data developed as part of this project.

Objective

(1) To make significant strides over the next three years in the development of hypermedia packages that assist students in non-science major courses to apply mathematics to science, appreciate the interdisciplinary nature of science, visualize the molecular nature of matter and the complexity of its interactions, and recognize the importance of science literacy in today's world. This includes:

> (a) Development of hypermedia modules covering material central to several non-science major courses in physics, chemistry, biology, and engineering, and core to science literacy. The development of modules will occur in approximately the following order and on the following time scale.
>
> - Year 1 – Basic skills, including mathematics, inductive and deductive logic, and scientific method.
> - Year 2 – Basic structures, forces, conservation principles, and symmetries.
> - Year 3 – Interdisciplinary science, science and technology, arts, humanities, society, and environment.
>
> Each module will include the necessary self-directed remedial work that some students need, without sacrificing the enrichment material that will benefit all students.
>
> (b) Interdisciplinary focus will be present, whenever possible, as will choices concerning the type and number of examples used, and depth of

treatment. This will make the package suitable for the underprepared student and well as one seeking only enrichment.

(2) To provide access to hypermedia packages in all UCSD libraries, instructional computing centers, and student dorms, via campus network operations.

(3) To develop an on-line image library of video segments, slides, animations, graphics, etc. that can be used to help students and faculty build hypermedia tailored for their use. This on-line multimedia library will also serve all California schools with access to CERFnet.

(4) To personalize instruction, and increase faculty/student communication by incorporating an E-mail system into the hypermedia package.

(5) To assess the impact of the hypermedia developed on student understanding, retention, and attitudes regarding science.

(6) To distribute the hypermedia and on-line images, text, animations, etc. as well as our experience gained in development to other institutions.

2.4

THE WORLD ENVIRONMENT INFORMATION SERVICE [*]

The United States has responded to the 1986 proposal of theInternational Council of Scientific Unions for an International Geosphere-Biosphere Program with "an interagency initiative of the Committee of Earth Sciences": The U.S. Global Change Research Program (related to The Earth System Science Program proposed by the Earth System Sciences Committee of the NASA Advisory Council in 1986). This program, which is unprecedented in magnitude, is a cooperative commitment of such agencies as NSF, NASA, and NOAA to support the observational, data management, and computing technologies and the disciplinary, multidisciplinary, and interdisciplinary research efforts necessary to develop a theoretical understanding and simulative and predictive models of global change in the geophysical, climatic, and biospherical state of the earth.

The Earth Fund has been interested specifically in the data management component of this ambitious and timely program since the efficient processing and distribution of data among disciplines and among nations is essential to scientific progress in understanding and modeling the earth as a system, yet national governments may have insufficient resources and initiative to develop an integrated earth information management system in the near future that meets the scientific need. Moreover, there is a need for an information management system that provides not only the scientific community, but also the private sector–i. e., businesses which utilize and influence the earth system, citizens and policy-makers concerned with the planet's future, and students and library patrons throughout the world–with convenient access to earth information.

The Earth Fund has plans to develop, in cooperation with the Institute for Earth Information and Ellery Systems, Inc., a World Environment Information Service of unprecedented scope and convenience. The World Environment Information Service will incorporate the same information management technology currently being deployed by NASA in the NASA Astrophysical Data System. This technology and its software is proprietary to Ellery Systems, Inc. (ESI) of Boulder, Colorado (the Systems Integration contractor to NASA for the deployment and implementation of the NASA Astrophysical Data System).

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[*] Proposal for a collaborative pilot project involving The Earth Fund, the Institute for Earth Information, and Ellery Systems, Inc., to develop a prototype for a world environment information service that has the potential to serve scientific, industrial, policy-making, and educational communities. Developed by Dr. Larry Goldberg, in collaboration with Ellery Systems, Inc., in 1989.

ESI's state-of-the-art information management technology integrates heterogeneous information systems, data bases, operating systems, etc. into a homogeneous, easily accessible system that requires little training and minimal computer experience on the part of the user. This technology provides a fully functional database management system, text editing capabilities, and other services, including the capacity to analyze all data and literature holdings of the system in accordance with the perspective of the user. The technology permits the construction of very large information systems and provides such systems with the inherent ability to evolve to meet to needs of future users through the incorporation of future services, analysis tools, and data and literature holdings. Access is supported for MS-DOS and UNIX operating systems and is anticipated for Macintosh and VMS operating systems. ESI licenses the technology to users and provides systems integration services to organizations wishing to make use of it.

The World Environment Information Service would integrate widely distributed, heterogeneous data holdings of State and Federal government agencies, universities, other public institutions, and private organizations. This service would be available to practicing scientists in university or other accredited research institutions, and students and educators in accredited educational institutions via reduced subscription rates. Access to the system by commercial and industrial users and government agencies not involved in scientific research and by private citizens and special interest groups would be by commercial subscription at rates not yet determined but anticipated to be competitive with existing commercial information systems and of such a level as to substantially offset and possibly exceed the cost of operating, administering and maintaining the system. The World Environment Information Service would provide these user constituencies with a homogeneous environment within which they could have access to a broad spectrum of environmentally relevant literature, databases, data sets, analysis tools, and other services. It is hoped that this improved access to environmental information will facilitate original research, interdisciplinary communication and cooperation, and dialogue among the various organizations, individuals, and special interest groups involved in contemporary environmental issues.

The user of The World Environment Information Service would be able to write inquiries of any length in his or her own words. The inquiry would be analyzed and assigned coordinates in a multidimensional space, the same space in which all literature and data set holdings are assigned locations. The system would respond to the inquiry with a listing of all holdings in order of how closely related they are to the user's inquiry document. Any of the holdings may be selected for display on the user's monitor, and any number of holdings may be edited and integrated by the user and printed for personal use.

Clearly, the World Environment Information Service not only would facilitate interdisciplinary exchange and wide distribution of scientific data and literature, it also would make scientific information about the environment available for the first time to the international public in easily accessible form. It is anticipated, therefore, that the World Environment Information Service will contribute significantly to scientific progress and public education regarding the environment. It also would become possible for businesses to have more economic access to information regarding the environmental impacts of their activities as well as their environmental opportunities. It is hoped that the potential contribution of the World Environment Information Service to the business world will help to motivate contributions and investments in the implementation of ESI's technology necessary to get the service started. The Earth Fund currently is raising funds for a pilot system which would provide selected environmental information in the context of three nodes, one for the atmosphere, one for the hydrosphere (oceans, glaciers, and land water), and one for the biosphere. A fourth node for the geosphere, to which a significant number of geographic data bases will contribute, will be developed at a later stage. Although the specific informational focus of the pilot system has not been decided, the role of ESI in the development of NASA's Astrophysical Data System would facilitate the availability of satellite data regarding the atmosphere, oceans, and biosphere. The pilot system might limit itself to such satellite data. Once this three node pilot system is installed, it will be possible to expand its holdings to include, for example, observations from land, literature as well as data sets and data bases, and other nodes.

The initial effort will require the architectural design and engineering design of the three node pilot, the participation of experts at specific datasites who will contribute information, data sets, and analytic categories, and the acquisition of sufficient computer processing equipment on which to construct the system. In addition, access to existing data transmission networks must be secured and adequate test sites must be developed to test the pilot system. System documentation must be produced, systems administration facilities acquired, personnel hired and trained, and user training programs must be developed and implemented. Finally, an adequate marketing program must be established and implemented, a business plan produced detailing the business structure and administrative programs necessary to support the project, and a comprehensive systems management and maintenance program must be developed and implemented.

Current estimates are that three months will be required to effect an architectural design and engineer the pilot system. Six months will be required to properly describe and index the data holdings to be initially made available, and three months will be required to bring the pilot system up to operational standards. From this point a minimum of six months will be required to adequately test the system so that decisions can be made regarding further service development and data holding integration. A minimum budget of $500,000 will be required to deploy a pilot system consisting of three primary nodes.

It is believed that the construction of such a system at this time will provide research, educational, commercial, and industrial segments with an extremely valuable information service. It is strongly recommended that the construction of the pilot project be undertaken with the direct participation of these user groups. This approach has proven exceptionally beneficial in the past as it permits the direct input of the user community into the design and implementation of the system. It has the added benefit of insuring a ready and enthusiastic user community prepared to participate further in the development of the system. This scenario insures that the users never feel distanced from the information system, that user concerns are integrated into the operational and administrative aspects of the system, and that the system develops over time specifically to meet the needs of the subscribing members. The credibility that the system will derive from this participatory partnership of builders, managers, administrators and users of the system will speak well for the continued support of the system.

Part 3

Selected Work-in-Progress

3.1 The Science and Philosophy of Global Change*

3.1.1 Introduction

The theme of *Global Change* has become an important one in scientific and policy-making communities only over the past few decades. There are at least four reasons for this partial transition from more specialized scientific concerns and more local policy-making concerns to an interest in global science and policy. First, as climate models began to indicate in the early seventies, it is likely that human activities, such as our growing consumption of fossil fuels, are contributing to climate change. That the carbon dioxide discharged from all the little smoke stacks and exhaust pipes around the world can add up to a significant increase in the global greenhouse effect alerted the scientific community as to the possible importance of many anthropogenic processes in changing the global environment. The possibility of studying global change that could occur in our lifetimes put a new priority on the mulitdisciplinary and interdisciplinary research necessary to improve our scientific understanding the interconnectedness of many environmental processes. Only through the study and modeling of the earth system as a whole could scientists hope to integrate the knowledge of specialized disciplines into an understanding of how social factors enter into the causal matrix of interactions that creates the state and evolution of our planet.

Second, along with the revelation that humans can change the composition, chemistry, and climate of the earth system came the appreciation that some cases of anthropogenic global change might not be good–at least for many of the social and economic groups most affected. A global warming, for example, would change the climate in different ways in different places, with potential impacts on agriculture and food supply in many areas. Health problems and starvation could be the result in many developing countries, with implications for political instability as well as human tragedy. The potential for negative impacts of anthropogenic global change alerted the policy-making community to take an interest in global policy. This put many policy debates, such as issues of energy policy, in a new light. Since

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*Introductory chapter of book of same title in preparation by author for use as a text in upper division and graduate global change courses.

there is a good deal of uncertainty about the timing and the locations of the future consequences of global–i. e., globally averaged–environmental change, the challenge to the policy-making community has been to find ways of considering the importance of long-term, internationally distributed impacts of a probabilistic nature.

Third, the rise of the environmental movement around the world has made global environmental policy concerns the political demand of what may be the first truly international political interest group. The popular interest in the environment has helped to motivate the funding of environmental science in many nations, which in turn has helped to educate people around the world via mass communications as to the beauty and rich complexity of our natural environment and its possible vulnerability to human activities. Problems of extinction, ecological disaster, pollution, and climate change naturally run together in the popular mind, creating something of a global audience for the newest scientific findings about the earth system. Although many scientists remain uncomfortable with their new role as planetary prophets, mass communications have irrevocably linked the scientific, policy-making, and environmentalist communities in a broader community. For lack of a better name, this broader community might be called the environmental education community. It is characterized both by internal conflicts and thematic unity. Among the conflicts are the tensions among the demands of the scientific community for precision, the demands of the policy-making community for assessments of economic risk, and the demands of the public for the preservation of our natural environment. Yet understanding, managing, and enjoying the social benefits of our global environment remain three complimentary perspectives that bring some unity to what I have called the environmental education community.

A fourth reason for the growing interest in global change is that the scientific community, quite independently of any social concerns, has gradually gained the capability over the past few decades of addressing extremely complex problems. This has been partly due to greater observation capabilities, such as the vast network of earth observing satellites that now serves the environmental science community. It has also been due, in part, to the growth of supercomputing capability that allows the development and testing of extremely complex models. These models often contain great spatial and temporal detail, many physical variables, and, by methods of numerical approximation, can solve many nonlinear systems of equations that would have been intractable before the computer revolution.

The result has been something of a second scientific revolution with a focus on extremely complex systems. Nowhere has the computational science found greater success than in the modeling of the earth system. This synergism between science and technology makes us wonder whether the technology that helped to create our environmental problems will also help us to find some solutions. Computational science in general and mathematical modeling of the earth system in particular face many problems, of course. These include inadequate data, inadequate understanding of the physical, chemical, biological, and social processes involved, limits of predictability due to the notorious *butterfly effect* (i. e., sensitivity to initial conditions), and limitations in computer speed, even in the case of the most advanced supercomputers. But the new science of complex systems and earth system science in particular are here to stay, with great promise for their potential contributions to scientific progress. Thus the potential for understanding the earth as an integrated system represents the hope, not only of providing the scientific basis for managing the planet, but also an area of science with great significance for the future of science.

If the emerging environmental education community, as I have called it, is a reality, formal programs of environmental education sadly lag behind the responsiveness of scientists, policy-makers, and concerned citizens. Perhaps education is the last institution to change, hesitating to bestow blessings on a new direction of knowledge until the proliferation of journals and programs in federal funding agencies make it unavoidable. Global change programs are still avoidable, but slowly they are beginning to appear at forward-looking institutions. Turf battles among geoscience departments eventually give way to the inevitable. The scientific study of global change, political commitment to respond to global change, and public concern about global change will not go away.

Some new programs and schools have been fortunate in integrating the contributions of a variety of disciplines and departments from the outset. However, it is not always politically feasible, or even scientifically and educationally desirable, to dissolve the boundaries of existing departments. Without specialized research, we will have no basis for developing an integration of specialized findings in global models. And without specialized majors, students will find it hard to sell their expertise in the "whole earth" when they graduate. The earth is too complex to be mastered as a whole by new generalists, no matter how broad their education. But the continued coverage of geoscience territory by the traditional departments of meteorology, oceanography, geography, geology, and so forth does not preclude cooperative development of new courses and programs of an interdisciplinary nature. The more successful of these collaborative education commitments may eventually justify their own faculty and courses and, especially at the graduate level, have the opportunity to institute new schools.

Whether new courses in global change are experimental departures from departmental offerings or components of interdisciplinary programs, they will need texts. To some extent, this need can be met through the eclectic selection of texts from a variety of earth-related fields. Ideally, however, it would be helpful if at least some of the texts provided an integrative perspective that helped to motivate the more specialized readings. This book is intended to meet that need.

3.1.2 The Relevance of Philosophy

This book (which I have called the *Science and Philosophy of Global Change* for a reason) has a second motivation. As an academic profession, the study of global change could benefit not only from a scientific focus, but also from a philosophical focus. Philosophy is avoided like the plague, of course, by most scientists. The result, however, is often an inadequate background in interdisciplinary methodology as well as an absence of method, or dependence on social science methods that tend to be utilitarian in presuppositions, in treating issues related to the ethical implications of science. Two areas of philosophy could come to the rescue here.

The philosophy of science has taken an interest in recent years in the interdisciplinary study of complex systems. The emerging research program has departed from the oversimplified hierarchical focus of systems theory and the overspecialized "Weltanschauung" or "paradigm" focus of conventional historical studies of science in its emphasis on intersubsystem and interlevel complexity and interdisciplinary theories, models, and methods. This orientation, informed by the comparative study of science (and reviewed in Part III of this book), may provide a helpful framework for considering many of the methodological questions that torment geo-, biogeochemical, and biogeosocial scientists concerned with global change.

Consider, for example, the challenge of integrating our understanding of the atmosphere, oceans, cryosphere, land surface, and biosphere–and the many scales of motion and change within them–to generate global models of the earth system. A philosophical approach to methodology could consider the relationship between the relevance of certain intersubsystem or interscale phenomena to the global behavior of interest and the need for interdisciplinary–as distinguished from multidisciplinary–model development. Philosophical analyses could help to clarify the relationships among empirical data, theory, and the results of mathematical models; among empirical, theoretical, and modeling disciplines; among the descriptive, predictive or retrodictive, and explanatory aspects of models; between the types of data and assumptions needed to develop models and the types needed to confirm them; and between the emerging global science research tradition and its many contributing disciplines and areas of science.

The are many methodological problems that warrent special attention. Philosophers as well as scientific methodologists, for example, must take an interest in the fact that models of complex systems generally don't predict from established physical laws alone. They use "parameterizations," or representations of relatively stable system patterns by many other names, to enable the predictions (or retrodictions) of models.[1] What is the status of these less-than-fundamental principles? Are climate models inadequate as scientific explanations because they employ such "semi-empirical generalizations"? A philosophical analysis could show how parameterizations have to be developed and tested in the context of their descriptive value as "curve fits" to physical data, their contributions to the predictive value of the

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[1] In climate models, for example, parameterizations represent the estimated consequences, at spatial and temporal scales resolved by a given model, of the mutual interactions between resolved phenomena and unresolved or otherwise neglected phenomena. Such parameterizations help to compensate for the impossibility of explicitly representing in a model all of the phenomena known to be relevant to the system behavior of interest; and they help to achieve the mathematical closure necessary to solve the equations of the model.

model they are part of, and their theoretical consistency with our understanding of the relationship between unresolved or otherwise neglected phenomena and the phenomena represented explicitly in the model. A philosopher would recognize that this role of parameterizations qualifies them–and the models they are part of–as conditional explanations, i. e., explanations that may work in some circumstances and for some purposes, but not necessarily in all circumstances for all purposes.

While freshman can afford to avoid methodological considerations such as the above, upper division students considering a new career focus–and graduate students pursuing one–had better not. Philosophical treatments of methodology could supplement scientific methodology and help it to pose fundamental questions and challenges to future practitioners. If the methodology of interdisciplinary global science is not to be as hopelessly chaotic as our endangered planet often appears to be, serious attention must be given to the methodology as well as the findings of the earth science disciplines. I believe (as a philosopher of science) that the philosophy of science has the conceptual resources to be of some help.

If the methodological issues surrounding the scientific study of global change have been too controversial to resolve within the geosciences, the ethical implications of global science often have been even further from professional treatment within the global sciences. Many responsible scientists, of course, have pointed out the uncertainties of their models and the potential risks that their predictions could represent for different social groups and economic interests. Yet it is one thing to point out possible impacts; it is quite another to evaluate their ethical significance and policy or management implications. Of course various areas of social science, including economics, policical science, sociology, and social psychology, have developed methods of policy analysis that are intended to facilitate the coupling of expert predictions and social interests or values. Too often, however, the presuppositions of policy analyses–such as what types of impact should be predicted and who should vote on their relative or integrated value, are not adequately clarified or justified. Many genuinely philosophical questions remain.

How can we assess the value of species, natural ecosystems, agricultural productivity, soil quality, fuel economy, economic growth, recreational opportunity, the health of sensitive populations? Do species, ecosystems, or the biosphere as a whole have value over and above their value to humans? How could such value be assessed? Do we have obligations to future generations? To future generations at probabilistically defined locations and times? Who should represent them on our decision panels? Indeed, how can we represent, in a consistent way, the range of social concerns from the most private interests and personal impacts to the most global and long-range concerns regarding the environment, biosphere, and future of civilization? What if different types of value must be informed by different types of scientific information–scientific information associated, for example, with different degrees of certainty or expert confidence?

Questions such as the above are not merely abstract philosophical issues, but actually must be resolved in particular policy-making contexts. We must decide how to assess the relative value of the various types of impact. But who should decide and on what basis? What is the relationship between predicted facts and social values? Should predictions, however limited in scope, suggest the definition of value dimensions? Or should values guide the choice of impact dimensions, however uncertain such prediction needs force scientists to be? How can we structure the interaction of scientists and citizens or policy-makers to yield appropriate policy analysis tools? How are scientific and social concerns to be integrated in a fair and scientifically justifiable way?

There are many such questions that don't have strictly scientific answers. Yet to appreciate the possible implications of global change–especially the forms of global change that environmental policy and management could influence–it is necessary to consider such questions as systematically as possible. Philosophical analyses could help to clarify issues regarding the relationship between scientific results and social values and critically evaluate the methods proposed to bring them together in policy-making and management contexts. It is my opinion (as an environmental philosopher as well as a philosopher of science) that environmental philosophy in particular may have the conceptual resources to help–if not in resolving value issues regarding the environment and the use of environmental knowledge, at least in identifying them in precise ways. It is essential to sensitize future scientists, policy-makers, and managers to the many value issues surrounding society's response to global change.

3.1.3 Global Change: Past, Present, and Future

As indicated above, much of the recent interest in global change is connected with a growing awareness of potential impacts of human activities on the global environment. Yet the discovery of many types of global change have been important throughout human history. Examples include the discovery (or rediscovery) of the earth's orbital relationship with the sun by Copernicus and Galileo, the discovery of the evolutionary origin of species (including humans) by Darwin, and the discovery (or rediscovery) of plate tectonic change just decades ago, as well as the discovery of anthropogenic contributions to global change by contemporary atmospheric chemists and climate modelers. Moreover, long before the advent of humans, the globe was changing in myriad ways. All the forms of global change are important to consider, especially in the upper division or graduate courses this book is designed to serve.

Although there are many ways to classify the types of global change, three broad categories are helpful to keep in mind. These are the physical (including chemical), biological, and social forms of global change. An example of the first type is the alteration of the earth's rate of rotation, the possible formation of a sea of hot mantle material, and other terrestrial consequences of a giant impact event that evidence suggests may have resulted in the formation of the moon from debris some 4.5 billion years ago. Examples of biological global change include the evolution of plants, animals, and fungi from unicellular organisms. Examples of social forms of global change include the industrial revolution and the contemporary revolutions in computing, information, and communication technologies.

Of course these three types of global change are not always independent. Evidence suggests that an asteroid impact that changed the earth's climate may have caused the extinction of dinosaurs some 65 million years ago, dramatizing the potential extent of biological consequences of physical events. The interactions between earth and life can go in the other direction when biological change influences the composition of the atmosphere, oceans, or land surface. A dramatic example is the gradual introduction of oxygen to the atmosphere, first by photosynthesizing bacteria and billions of years later, by photosynthesizing plants. As we know, the physical conditions of the earth and human society also interact. Anthropological evidence suggests that human migrations were often influenced by climate change, while humans are now contributing to a global warming through their consumption of fossil fuels and the resulting enhancement of the greenhouse effect associated with increases in the atmospheric levels of carbon dioxide. A warmer climate will, in turn, have consequences for natural ecosystems as well as for agriculture. Humans also contribute more directly to biological change, as when the destruction of large areas of rain forest cause extinction of tropical species. And biological change influences society, not only in the obvious cases of agricultural productivity and the recreation value of natural ecosystems, but also as a result of alterations in biogeochemical cycles that may follow from the destruction of vital components of the biosphere.

Physical, biological, and social forms of past global change and their various interactions–from the origin of the solar system to the emergence of humans–are the focus of Part I of this book. Turning from environmental to human history, Part II will review many of the ways human civilization has responded and contributed to environmental change. Part three will review some of the major findings of areas of research that model environmental change, with a focus on predictions of future global change, the methodological issues connected with such predictions, and the ethical and policy issues related to the potential impacts and scenarios of possible futures they suggest.