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SYSTEMS SCIENCE CONCEPTS AS UNIFYING TEACHING THEMES: INTEGRATIVE SCIENCE GENERAL EDUCATION

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ABSTRACT: INTEGRATED SCIENCE GENERAL EDUCATION PROGRAM (ISGE)

The proposed ISGE Program is designed to answer several important needs simultaneously. National leaders of academia, government, and industry have deplored the level of science literacy and preparation in the nation's non-scientists. Modern science and engineering is increasingly characterized by interdisciplinary research but all training programs are disciplinary-based. On-campus critics have lamented the smorgasbord character of our current General Education program and many national-level universities are in the throes of redesign of the their GE. Interdisciplinary courses of study themselves face several inherent obstacles that diminish their efficiency, frequency, and longevity. The supposedly integration-oriented systems science community is itself fragmented and fragmenting further as well as in need of exemplary systems education programs. The ISGE program is specifically designed to overcome these specific problems or answer these needs with a model program that could be replicated nationally.

The ISGE program has as its major goal that non-science students achieve a deep understanding of the scientific method through the study of the most important theories and mechanisms of Astronomy, Physics, Chemistry, Geology, Biology, Computer Science, Mathematics and Statistics, *integrated not by discipline, but rather by common features across the disciplines*. The 30-week course of study and laboratories will use a ***dozen systems concepts and processes to unify*** the conventional natural science knowledge base in a innovative and unique manner. It also thoroughly presents the impacts of science and technology on the personal life of each student and their society illustrating how social systems also utilize the same systems concepts and processes as do natural systems. Students finishing the course of study will experience repeatedly how nature and man are part of a truly unified total system. They will learn about natural systems and systems science simultaneously.

The program will consist of a three-quarter sequence of three interdisciplinary science lecture courses, three associated activity-discussion or problem-solving segments, and one interdisciplinary lab in a fully integrated package. All segments are inseparable and interdependent. Although packaged in familiar, bureaucratically necessary form, the various class types are unusual. There will be no lectures. Information transfer will rely primarily on hypercard-based, extensively laser-disc-&-CD-ROM-illustrated, self-study computer modules (interactive multimedia). These will be prepared in an initial, externally funded, content-development phase before the courses are offered. This intensive content preparation will insure adequate cross-linking and synthesis, diminish later faculty "burnout", and reduce the number of faculty needed to still achieve interdisciplinary team teaching -- all factors that will increase the efficiency and longevity of the program. The student and faculty discussion segments, and the activity-discussions across the entire year are an extension of the "modular" segment for increasing understanding and practicing problem-solving. The labs occur throughout the year, not just in one quarter to allow further integration. Math does not occur as a separate course of study because it is fully integrated throughout the year with the information from all of the seven sciences covered, which themselves are not covered separately, but as "facets" of the integrative themes. Still, the needed rigor and identity of each discipline will be maintained by student choices from a library of 146 in-depth case studies, each presented in a 30-minute multimedia module. The ISGE program will serve to fulfill all 16 units of the usual General Education science requirement in one year (including Statistics 120) for non-science majors in 30 majors from four Colleges, particularly those in

arts and business. Enrollment for this team-taught course is expected to be 150 maximum per year in a self-contained, *de facto* Honors program.

The proposed ISGE Program has the following unique and innovative features: (1) It presents the students with 12 integrative themes that are general, universal scientific processes/mechanisms and demonstrates how these are common to all seven science disciplines. *These integrative themes are of interest to the ISSS and to Systems Science because they are all systems structures or processes from our unique and special knowledge base!*; (2) It provides the students with choices from a "library" of case studies (on multimedia modules) that are concrete and pedagogically sound examples of each theme from various points of view and in the phenomena of each of the seven sciences (see Tables); (3) it involves the students in problem-solving activities which reinforce each theme and develop lifelong skills; (4) it teaches basic mathematical concepts as well as providing examples of the vital role that mathematics and statistics play in the pursuit and application of all scientific knowledge; (5) it combines self-study technological modules with faculty debates, intensive student discussion, theory with practice, and study in "specifics" with simultaneous study of "generals."

The finished ISGE program as presently planned will provide over the year of study: 75 mini-case studies in the physical sciences, 37 mini-case studies in the life sciences, 27 mini-case studies in mathematics and computer science with 34 hours of practice in statistics, and thoroughly synthesizes this information using twelve thematic processes while linking the science throughout with its possible impacts on students and society in each and every module. Keywords: systems science education, natural systems, general education, natural sciences, integrative themes, multimedia-hypermedia modules, systems science institutions.

PRACTICAL EXPERIMENTS IN SYSTEMS SCIENCE EDUCATION ARE NEEDED

One lesson looms large over the past 30 years of attempting to build a science of systems. Our work in the ISSS is futile unless we first build a series of healthy and stable institutions that evaluate, faithfully replicate, and improve and/or apply its special knowledge base. Through these institutions must pass an ample and sustained number of students if systems science is to survive and evolve.

Our recent record in this regard is poor. Past systems science education programs have been either severely curtailed or disbanded. The Systems Science Institute at the University of Louisville has been closed. The Systems Science Dept. and systems-based international degree program at the Institute for Safety and Systems Management at the University of Southern California (USC) has been significantly reduced. The systems management program at the Wharton School of the University of Pennsylvania has been terminated although its mentor, Dr. Ackoff, has moved the heart of the program into his management corporation. An entire College of Systems Science was initiated at the University of Denver only to be closed within three years of its opening. The Cybernetics Systems Program at San Jose State University has been recently closed down after granting well over a hundred Masters Degree's. The Cybernetics Management Program at George Washington University in Washington, D.C. has long since reverted to a more conventional program losing much of its systems emphasis. Our own California State Polytechnic University Minor in Comparative Systems Analysis has never enjoyed the flow of students needed for it to stabilize. There are probably many more than these seven examples of systems education programs gone awry or not reaching their potential.

Among the few programs that have survived, the strongest may be the Dept. of Systems Science at SUNY, Binghamton, the Systems Science Ph.D. Program at Portland State University, and the Informatics and Systems Science Program at Stockholm University. Even these at latest report were subject to large fluctuations in demand, that is, year-to-year variations in enrollments. In times of reduced resources such as these, programs with modest student demand are scrutinized for elimination or scale-down. Such decisions are hastened even further by the unconventionality of systems science. There is no such heading in the Library of Congress Listing of Subjects and no such category in the Dewey Decimal System for such a heading. This author has met with representatives of the Library of Congress to institute such a heading soon, and the I.S.S.S. was first successful in establishing a Hegis Code for Systems Science only recently.

It should be clear that the combination of little awareness of systems science in K-12 and undergraduate education of students and the lack of awareness in the larger society is deadly to our enterprise. Even within our own community there is not a clear consensus on what specifically should or might be taught about systems science on what levels, and not even a clear program of mechanism to build toward such a needed consensus.

STRATEGIES: INCORPORATION OF SYSTEMS SCIENCE INTO THE MAINSTREAM

Different systems professionals have used different strategies to effect the inclusion of systems concepts and processes into conventional education. Many of these fall into a couple of basic dichotomies, such as the following: undergraduate-level or graduate-level, course-cluster or major, department-structure or soft-funded-Center/Institute. Our choices for the ISGE Program in this series of dichotomous decisions are "undergraduate", "course-cluster", and "Institute." It is important to explain why we have chosen these particular institutional features for this particular effort in view of the above described fate of many systems science programs.

Arguments for establishing mainly graduate programs in systems science are reasonable. They state that students need a high level of maturity to understand systems, that systems research is best carried out at the graduate level, that respect for the depth and rigor of the unconventional systems program is best earned if the effort is at the graduate level, and that training for jobs in systems is best carried out at this level. It is not surprizing that the two U.S. and one Swedish program that have survived are at this level. However, even these programs are beginning to consider establishing undergraduate alternatives for a very simple reason. Without such programs there is no reliable provider or "feeder" population. We will carry this argument even further in a forthcoming paper. The place to start systems education is in the K-12 sequence as part of the conventional program of study. Thus, this proposed program begins with teaching systems science at the undergraduate level to even non-science, non-technical students as a testcase on whether or not students can be attracted into the systems sciences in future generations.

In the following sections you may note how defferential this proposed series of courses is to the science departments at our university. We have deliberatly chosen to cooperate with and build upon their excellence rather than to challenge or compete with them. Selection of a course series not a major, and housing it in an Institute rather than attempting to form a new Dept. further enables cooperation not competition. Finally, focusing on "general education" insures a steady and rich supply of students, some of whom would then be attracted to take the Comparative Systems Analysis Minor offered by our Institute. We hope these features will enhance the longevity of this program.

USING SYSTEMS PROCESSES TO UNIFY THE CONVENTIONAL SCIENCES

Integrative, Synthetic Themes - ISGE plans to use at least 12 clusters of cross-disciplinary mechanisms or processes which are found in all seven of the sciences to integrate their diverse phenomena. Many of these themes were cited in Chapter11 of Project 2061: Science For All Americans: Literacy Goals in Science, Mathematics, and Technology written by the National Council on Science and Technology Education and sponsored by the American Association for the Advancement of Science [1]. Criteria that the ISGE Working Group used to select these central themes included the following: Themes must be: (i) mechanisms or processes with important functions in natural systems, (ii) found in at least four of the seven sciences covered in the course -- cross-disciplinary (preferrably themes should be found in all sciences - transdisciplinary), (iii) understood in sufficient detail that "deep" information about the theme is available, (iv) potentially integrative, that is, the identifying characteristics of the theme are clearly seen in a diverse enough set of examples to support the argument that the special cases are all variants of a more general, unified case, (v) capable of supporting detailed case-studies that non-trivially deliver explicit understanding of important phenomena of each conventional science discipline represented, (vi) rich in available illustrations and demonstrations, (vii) useful in promoting understanding of the impacts of science on society, (viii) useful in improving our understanding of social systems, thereby integrating both natural and social systems, (ix) representative of an interesting advance in human knowing. Additions, deletions, and rearrangements of currently listed themes will be encouraged throughout the next three years of development.

Table One illustrates some of the systems science processes we hope to use to integrate conventional science subject matter. Along the left vertical axis you will find the systems unifying themes. Along the top axis you will find the seven participating sciences. Within the boxes that mark the intersections of each theme with each science you will find a very succinct phrase describing the case study or studies we hope to use to illustrate the systems process in each particular discipine. Take the fifth theme, for example, regulatory mechanisms and feedback. We will begin by introducing the concept of feedback, its identifying characteristics, its function in systems-in-general, its examples on the human level, and its usefulness in helping us understand a particular new area of knowledge. Then we will guide the student through a series of computer-based training modules that are extensively illustrated and animated which show that ***the very same identifying features and functions*** of feedback are found in common across important phenomena of the seven sciences. We will use specific examples of feedback in galaxy formation and dynamics, in star formation and dynamics, in nuclear fission reactions, in chemical metabolic reactions, in cell growth that is normal versus that which is cancerous, in body temperature, in ecosystems, in the GAIA hypothesis, in program control statements, and in limits to computer use due to computational explosion. For each of these we will emphasize student competence in the phenomenon of the discipline, and student understanding of the systems process, but most of all student recognition of the similarities and differences between the sciences. Students will be learning a great deal about conventional science and an innovative new way to approach natural systems via systems science at the same time with the same effort. The similarities should help simplify the usual topical material for better assimilation, understanding, and usage.

Table Two illustrates some of the features of the scientific method and mathematics that we hope to use to integrate conventional science subject matter. Along the left vertical axis you will find the features of the method. Along the top axis you will find the seven participating sciences. Within the boxes that mark the intersections of each feature of the scientific method with each science you will find a very succinct phrase describing the case study or studies we hope to use to illustrate that feature of the method or of mathematics in each particular discipine. Many of these case studies will instruct students in crucially important phenomena or theories of the conventional sciences. Each case study of both Table's One and Two will also include a final portion that compares the natural systems process with similar processes in social systems thereby relating all to the students personal and civic life. Browsing these tables will show the extent of case study coverage.

INTEGRATED SCIENCE GENERAL EDUCATION AT CALIF. STATE UNIV.

The following list of 33 features presents a summarized, although as yet fragmented view of the program proposed to-date. The features are the current consensus of the Integrated Science Working Group composed of 27 Faculty. This includes 18 College of Science faculty from six science Dept.'s representing the fields of Astronomy, Physics, Chemistry, Geology, Biology, Computer Science, and Mathematics and 7 non-science faculty from the 3 additional Colleges of Arts, Business, and Engineering.

(1) Annual enrollment will be limited to 150 students, consisting of qualified first-time freshman and possibly some first-time transfer students; invitations will be mailed and students will respond by interviews; this feature will protect the territoriality and FTE of the participating conventional departments. This is an "alternative" General Education program, not one required of all students.

(2) Pre-requisites for admission would be 3.0 G.P.A. at entrance, and passing scores on the Writing and Elementary math exams. The program is primarily designed for entering Freshman and transfers who have not yet taken their science GE. Science majors would not earn credit toward their degree for taking these courses. Under these circumstances only a small number of science majors would participate further protecting FTE of conventional departments.

TABLE ONE: SYSTEMS PROCESS UNIFYING THEME BY CONV. DISCIPLINE

SCIENCES → / ↓ THEMES	ASTRONOMY	PHYSICS	CHEMISTRY	GEOLOGY	BIOLOGY	COMP SCI	MATHSTA
HIERARCH . SCALES OF SIZE	galaxies, stars, planets; moons; ast.; clusters	families of subatomic particles; atomic str	elements; compounds; polymers; multimers	geologic time hier; landsat to crystallog. hierarchy	organelles; cells; tiss. org.; org's; ecosystems	stepwise refinement; subprogram , sys. str.;	log scales; metrics; nested equations
MODELING REALITY: CAUSES & CHAOS	chaos in planet orbits	turbulence in flows; chaos in snowflakes & faucets		chaos in weather sys	chaos in muscle & heart-beats	how the comp helps us "see" chaos	universal quantities in chaos
SYSTEM DYNAM-IC'S & BOUNDS	gravity as action at a distance;			effects of asteroids on planets; greenhouse effects	membranes of cells; the skin eco-ranges; interactions	computer networking;	concepts of limits; fcn's as interaction
SELF-ORGZ ORIGINS & EMERGENCE	origins of the solar system; starbirth; cos heterogeneity		coacervates; hypercycles	volcanic isles mech.'s of orogeny;	autocatalysis of organelles; new species; macroevol;	artificial life games; pattern recognition;	
REGULA-TORY MECH AND FEEDBACKS	stellar feedbacks;	nuclear fission rxns;	end-product inhibition;	Gaia & bio feedbacks to geo;	hormones; embryology; eco food web	program control statements;	computation explosion;
STABILITY & EQUI-LIBRIUM	Hertzprung-Russell diag stellar stabilities;	thermodynamic equilib; phys. stasis	balancing rxn equations;		dynamic equilibrium MTS; homeostasis equilib. in ecosystems;		math. of dynamic equilibrium;
CYCLES & OSCI-LLATIONS	galactic life cycle; stellar life cycle; oscillating cosmos	states of matter;	transitions, phase diagrams;	crustal re-cycling; bio-geochemical; ice-age cycl.;	organism life cycles; species, eco sys life cycl	recursion loops in prog;	math. of oscillations;
DUALITY, SYMMET. GROUP TH.	binary stars; matter vs. anti-matter; asymmetry;	opposite spins; wave-particle dual;	optical activity; + and - charges; ana-catabol -ic rxns	dual forces in storms; crystal form symmetries;	complementarity in dna; gene info tra bilateral sym neuropeptides	duality in programming	group theor. duality in algebraic sets; geom. & Poncelet;
LIMITS, CONSERV. ON FLOWS	universal constants; anthropic principles	physical limits; entropy laws;	chemical information		biopolymers as info,	history of information theory; limits of computing	math of info theory;
INTERACT NETS & FIELD TH.	gravitational fields;		types & basis of chemical reactions;	multiple effects of CFCs	ecosystem structure; dev'tal gradients;		
FORM, PROPORTION & CHANGE	closed or open univ.?;	engineering allometry;			biological allometry; neural nets;		discovery of the calculus;
MECH OF VARIETY AND EVOLUTION			chem competition & selection;	punctuated equilibrium, Burgess shale	discovery of evolution;	genetic computing algorithms;	how chance generates variety;

TABLE TWO: FEATURE OF SCIENTIFIC METHOD BY CONV. DISCIPLINE

Sciences→ / ↓Method	ASTRONOMY	PHYSICS	CHEMISTRY	GEOLOGY	BIOLOGY	COMP. SCI	MAT/STA
Character-istics of Scientific Method	vast holes & great walls, solar system spectral lines	cold fusion; subatomics; motion laws; coop. labs; doppler&red	evol. of atomic th., millerurey expts, simpl chem models	continental drift; fate of Wegener; coop. labs	protein genes ultracentrifu-gation; origin of life; spon. generation	seeing mult-dimensional objects	-calc.'s in thirteen dimensions
History of the Scientific Method	discoveries of galileo	influence of Newton to Einstein	alchemy to science	influence of one sci on other, evolution	reduction; exemplary expt's of Pasteur	impact of birth of computers on sciences	birth of math; use of formulas Archimedes
Current Practice of Scientific Method		strong inference in atomic th.;	strong inference in molec. bio.;	solar system exploration & geo mechan's	synthesis of EO Wilson;	synthesis of HA Simon; Hoftatdter	synthesis stories of Leibnitz; Poincare
Models of Doing the Scientific Method		disproving ether; light bulb, edison ;	disproving flogiston;	nets of consistent evidence - geo + bio	disc. reverse transcriptase antibiotics exaggtd fcn;	parallel com-puting;	-
Limits of Scientific Method	unanswered cosmological questions;	Heisenberg & uncertainty		piltdown hoax;	cancer biol;	computing limits;	Goedel's theorem; twin studies
Chance & Probabil. in Science Methods		character of non-living populations			character of living biosoc populations		types of noise; mech of chance & probability
Sc. Meth. Impacts on Worldview Philosophy	trial s of Galileo; the anthropic univ.	universalism vs nominalism reductionism	Wohler syn urea;		cell engineer-ing; Cuvier & Owen vs evol	-	determinism vs chance
Values or Ethics & Scientific Methods		lasers in star wars vs med-icine; nuclear power;	chem/pharm industry vs pollution;		when do we die; when did life begin?; bioengineerg testube baby	privacy vs comp. power; high finance & computers;	
Paradox's and the Scientific Method		waves vs particles; matter & energy,					mathematical paradoxes;
Sc. Meth.- Spectrum of Ways of Knowing		why its called metaphysics ; Feynman discoveries	Kekule disc. ring str's,				
Applic. & Products of Scientific Method		new energy sources;	contributn's of polymer chemistry;	finding gas; predicting earthquakes;	recombinant DNA industry curing dis-eases;	increases in computing powervs cost	unexpected practical use of high theory
Future of the Scientific Method		teachings of Bohm;		macro-scale weather modeling	teachings of Jantsch;	learning sys science thru expert system	math & systems science

(3) Students would be organized into 30 students per section, for five coordinated sections earning 5 faculty.
(4) Many majors on campus could not take this course series because their curriculum specifically requires certain science courses (eg. Ag, Eng). This would leave untouched most of the service FTE of the participating science departments.
(5) The Central Objective: to show the natural structures/mechanisms/processes that are common or similar across seven sciences giving a detailed impression of the unity of the sciences and of natural reality, while still teaching the major phenomenon of each of the seven participating sciences.
(6) Series of courses will satisfy the full 16 units of Category II GE shared as a requirement for the 376,000 students of of 20 campus C.S.U. system.
(7) Course series will be designed to be completed in one academic year to reduce attrition.
(8) Three quarters duration must be taken successively; succession required unless exceptional circumstances
(9) First quarter = 5 units; Second quarter = 5 units; Third quarter = 6 units
(10) The Standard quarter would be comprised of, 4 units "Lecture" + 1 unit "Activity"
(11) Three, 3-hour interdisc. labs per quarter; on alternate weeks; graded as SP (sufficient progress) in Fall & Winter Q's, credited fully in Sp Q for 1 unit
(12) Nine weeks each quarter would have weekly 2-hour skill-training, Activity-Discussion and Problem-Solving Sessions; often on applying systems thinking, using mathematical reasoning and understanding of statistics integrated with particular science phenomena.
(13) Capstone quarter: Credit for multi-quarter labwork, and for completion of Portfolio research or application project. However, writing for this long-term project will result from weekly writing assignments throughout course series, each requiring application of concepts of the week to the research topic selected
(14) Mathematics & Statistics will be integrated throughout course; not as a stand- alone course; found esp. in 2nd Q Scientific Method outline, and in all Activity-Discussion sessions; Complete coverage of STA 120 topics (usual beginning stat course).
(15) Interdisciplinary Laboratories will be integrated throughout course, and not occur as a stand-alone lab quarter; all labs would have protocals from most of the five experimental disciplines, but each discipline would give an experimental demonstration of the same systems process for that week.
(16) Interdisciplinary Teaching Teams of 3 to 5 science prof.'s per quarter representing four of the six Science Dept.'s; rotate rep's each quarter.
(17) Design Teams; paid as consultants from external grants; responsible for producing 'stable' "interdisciplinary" *scripts* for teaching modules.
(18) Design of case studies, outlines, and *scripts* in a particular disciplinary area are primarily under the direction of ISGE faculty members in that disciplinary specialty; cross-disciplinary references and improvements will be included as well as review by other disciplines to enhance integration.
(19) All *scripts* will be reviewed and extended by Prof. from other Colleges (primarily Arts and Engineering) to insure significant integration with those required areas.
(20) Every *script* will have fundamental performance spec's that require it to demonstrate linkages with the integrative theme, linkages with other disciplines, illustration of the scientific method, and impacts on society and values; so each case study is simultaneously a depth study and a unifying study.
(21) Teaching Team members will be reassigned from Dept's; Dept's will be fully reimbursed; Prof. chosen by self-selection; ISGE will reserve positions with Dept. Chairs one year ahead.
(22) Both Teaching and Design Teams will be initially drawn from the 27 Professors of the ISGE Working Group who have already invested in project augmented by those who join pool later.

TYPICAL QUARTER: GENERAL PLAN

(23) Each quarter begins with a detailed and comprehensive introduction to the objectives, methods, requirements, and overall picture of the course for the quarter and how it fits into the course series.
(24) Each quarter also begins with small group sessions to increase computer literacy and comfort with operating the multimedia modules.

(25) Weeks 1 and 2 (every quarter)...increasingly detailed study of the scientific method using depth case studies of each feature from different disciplines (6 weeks duration by end of year); it was decided to distribute study of the scientific method over the entire year of study rather than take up entire first quarter on just this topic (see Table One).

(26) Weeks 3 to 10 will be taken in two-week cycles every quarter...each two-week segment will introduce an integration theme or unifying mechanism (systems process) followed by case studies from at least three of the seven sciences.

(27) Students will be able to make their own selections of case studies from a library for each two week segment with some constraints that ensure selections are adequately diverse over the year.

(28) TYPICAL PLAN OF THE TWO WEEK CYCLE

Mon Tues Wed Thur Fri

|<-->|
Integrative Theme Intro Module + One Case Study (1st week)
|<-->|
Two more Disciplinary Case Studies (2nd week)

|<--------------->|
Discussion Sessions

|<----------------->|
General Assembly

//
This part is independent study; by computerized modules each week

///
This part is face-to-face or activity

//
"Activity" or "Interdisc. Laboratory" scheduled in small sections every other week

(29) Integrative Themes were selected from recent national commission studies of science education by AAAS for Project 2061 [1], and from two decades of study by our own Institute for Advanced Systems Studies.

(30) The Case Studies which illustrate each theme for each of the seven disciplines in depth and rigorous detail, and also illustrate each point in coverage of the scientifc method, were suggested by science specialists from every dept. on ISGE Team (see Table's One and Two).

(31) General Assembly Session; 1 hr. per week; all prof. on Q team meet with all students (and often guests from other knowledge domains) for prof. debates on integrative theme, its relation to disciplines, and its impact on science and society.

(32) Discussion Sessions; 1 hr. per week; each prof. meets with a small group for more personal student discussion of weeks information and for help. Prof. rotate to a different small group each cycle.

(33) Independent Study Modules will be computerized multimedia using simulated hypercard instruction, animations, LD-ROM illustrations, sound, and diagnostic testing for competency and will allow students to move in a non-linear, choice driven manner through the module.

I.S.G.E. INTERDISCIPLINARY TEACHING METHODOLOGY

It is critically important that the method used to teach and learn match the content. For the ISGE program, since the content is decidedly interdisciplinary, even transdisciplinary, the methods must also be rigorously interdisciplinary. Herein lies a problem. There are several valid and reoccuring criticisms of or obstacles inhibiting past attempts to be interdisciplinary. These include: insufficient representation of specialties or disciplines, lack of rigor, lack of depth, rapid faculty burnout in team teaching, inability of teams to sufficiently synthesize course material as they teach, and poor long-term stability of programs and courses. Teaching methods for this course series have been specifically designed to overcome these common obstacles in a synergistic manner. The following ten features would substanially lessen the impact of the common problems.

(1) ***Interdisciplinary Scripts*** - Our 20 years of experience in attempting to design and deliver interdisciplinary courses evidence that the use of "scripts" greatly enhances the production of more fully integrated or synthesized curricular material. "Scripts" are the written product of teams of professors and describe the knowledge and illustrations in detail used to accomplish learning in a defined topical area. "Scripts" are stable so that they may be reviewed by many specialists who can check to be sure their material has been appropriately and adequately integrated. More material can be integrated. All design team members can improve scripts simultaneously which shortens development time. When controlled by a specific list of shared performance criteria, "scripts" can be altered until they precisely accomplish objectives.They can be transferred to teaching faculty without loss of detail. "Scripts" improve the replicability of courses across quarters, years, and even institutions so that standards of quality are maintained. They allow for extensive review and correction of material and intentional design changes that can then be tested and verified or discarded. "Scripts" are especially useful in multimedia productions such as those suggested here because they allow continual addition of better examples of the material using visuals, graphics, motion studies, and audio from an ever wider team of contributors. It takes a great deal of time, much effort, and some inspiration to integrate any material, and "scripts" provide the necessary ingredients that increase chances of success.

(2) ***Case Study Methods*** - Use of case studies is a proven method to give students a very real and detailed sense of a general principle in action in a particular instance. They are a proven technique for giving students an example of problem solving in that they usually state a problem, show how it was solved, and how the human expert went about solving it. Case Studies bring abstraction and generality to life. Interdisciplinary courses dwell on "generals" so they need "case studies" as a counterbalancing format that allows rigor, specificity, and welcomes applications. Criteria that the ISGE Working Group used to suggest more than 100 case studies for this course series included: They must (1) focus attention on an important theory, principle, or process in one of the disciplines; (2) provide a vehicle for delivery of significant facts and findings on that phenomenon; (3) provide an example of science, the scientific method, or of specific scientists in action; (4) teach a lesson about humanity or human reactions to science; (5) be a rich source of intriguing illustrations, graphics, or motion studies; (6) be capable of stand-alone presentation without a vast prerequisite knowledge; (7) but be arranged in a sequence that helps students to understand any one discipline more widely and deeply as the course series progresses. We expect individual case studies to range from 15 min to 50 min duration each. Like themes, alterations and improvements in the Case Study Library will continue over the years.

(3) ***Team Teaching With A Twist*** - Only a small number of the faculty in any specific science discipline are interested in interdisciplinary teaching. Even a smaller number are accomplished in the special skills necessary for effective interdisciplinary teaching. Furthermore, interdisciplinary types may be very good at overview, but found wanting by their reductionist colleagues in specificity. If a program relies on these same individuals for too long, burnout occurs, and the program eventually fails. If only generalists contribute to "scripts" an important and critical dimension of the sciences is lost. In the ISGE program the interdisciplinary team teaching in any one quarter is only the tip of a very real iceberg of collegial support. The technological modules are responsible for a great portion of the most important synthetic and integrative material. These have been prepared by a much larger design team of both generalists and specialists working on the same set of performance criteria. In this way, a wider range of faculty can participate without loss of integration, or overview, or specificity. There is also possible a much greater fidelity to a high standard of interdisciplinarity across course offerings and consistency of presentation and expectation from one course to another. Still, these courses do not rely on the "canned" aspects of team teaching. As explained below the "live" interdisciplinary team works closely with students for about two-thirds of the course time over the year, given the laboratories and activity-discussion sessions. These are all team taught.

(4)***Self-Paced, Interactive, Non-Linear, Self-Study Modules*** - In a conventional lecture, students must proceed at the pace set by the instructor, and in a direction that is always determined by the instructor. Some studies show improved learning when a student can personalize the pace, interact with the material in a variety of ways, and feel in control of the direction or sequence of the material through personal choice. Active learning wins over totally passive learning. All ISGE courses are designed for active learning. Today, laserdisc technology allows the linkage of as many as 300,000 pages of text on one disc, or tens of thousands of high quality slides and short motion sequences. With recently appearing compaction programs, complicated illustrations can be reduced to a few kilobytes of storage greatly increasing capacity and retrieval times. When added to the above described hypercard format, this technology gives students an incredible diversity of stimulating alternative examples of every academic point and a wealth of choice for active learning. Once the hypercard scripts are produced in the former stage, work can begin on accumulating many examples of each theme and case study. These collections can then be reproduced cheaply in subsequent diskettes, laser discs, or CD-ROM's and distributed.

(5) ***Emphasis on Human History and Extensive Illustrations*** - If you examine books of Popular Science, you may notice that the best-selling books have two features in common. They emphasize the human interest aspect of science by tracing the discovery of important new ideas through personal life histories. They also include many attractive pictures and diagrams that have teaching value in their texts. Since our target population are non-scientists, we plan to use these same features in our teaching modules without losing the accuracy and detail needed for appropriate science education. The technologies we have selected enhance our ability to do this successfully.

(6) ***Self-Testing and Mastery As Pedagogy*** - Some of the most efficient and most carefully verified teaching programs available are coming not from educational institutions, but from training programs in high-tech industries. These programs use mini-quizzes embedded in the tutorial programs that enable students to monitor their own progress, diagnose their own needs, and immediately respond to those needs by re-learning. They also require mastery of any one set of material before advancement to the next. Again, the technology we have selected enables the inclusion of these features in our tutorials. The advantages to be gained from such a feature will be more likely achieved given the stability for analysis provided by interdisciplinary "scripts."

(7) ***General Assembly Debates*** - The emphasis on technologically-mediated lessons leaves some educators cold. Where is the human dimension? This human dimension may be especially important in education of non-scientists who already have a stereotype of scientists as lovers of machines who are poor in human qualities. So each week of the ISGE program is divided equally in time between the self-study, tech modules and "live" human interactions. In this way the advantages of both techniques are gained without suffering the absence of either. Each week a debate will occur before the entire ISGE student body on the topic of the week. Since each theme occupies two weeks of class time, the first week's debate might be among members of the several science disciplines concerning the integrative theme and its nuances in each science, while the second week could be between science faculty and "guests" from non-science faculty, such as those who could vigorously represent engineering-business applications, or arts-humanities issues.

(8) ***Student Learning-Through-Discussion Sessions*** - Also once per week, smaller groups of 20 to 30 students will meet, each with a member of the interdisciplinary faculty, to discuss the integrative topic of the week. This time and size of group will allow for more questions and answers, more student dialogue, and more personalization of the course material. Team members will use nominal group discussion techniques so that such sessions do not degrade. Faculty will rotate through the discussion group sessions so that all groups will spend two weeks with a member of the faculty from each science by the end of the quarter. These "live", human-based sessions each week will also counterbalance the technological portions of the course.

(9) ***Interdisciplinary Activity-Discussion Exercises*** - One of the main characteristics of science that is important for non-scientists to experience is its emphasis on and success at problem solving. Each week a 2-hour session will be devoted to practicing student skills in problem solving and applying the integrative theme and case studies of the week. Since each theme and case study set runs for two weeks,

students will practice problem solving for a total of four hours for each set. Many of these exercises will be at the interface of the theme topic and standard statistics and probability because these skills are so fundamental to understanding all of the sciences. The problem solving exercises will also emphasize applications of this knowledge to a citizens daily life, since we are not trying to create "little" scientists, but rather help non-scientists appreciate and use science.

(10) ***What Is An Interdisciplinary Lab?*** Every three weeks students will experience one 3-hour laboratory. It was decided to place each lab in the same week that its integrative theme was under study. It was also decided to give the labs throughout the period of learning activity to enhance the feel and reality of integrating the material. Each lab will have a set of short protocals for the student to perform, and a set of demonstrations of an integrative process in each of the seven disciplines (where possible). The difference in apparatus and subjects for each protocal will emphasize how the sciences differ for the student, but the simultaneous similarity of the process studied in the different subjects will emphasize the continuity. Any data collected may be used for statistical analysis or evaluation in the next activity-discussion session thereby unifying the two different experiences. These labs will be unique because unlike standard labs in any of the sciences they will demonstrate the same mechanism to be active in phenomena from several different disciplines using widely differing methodologies and instrumentation.

INSTITUTIONAL ARRANGEMENTS TO ENABLE THE I.S.G.E. PROGRAM

(1)***Cross-Listing for ISGE Courses*** **-** We intend to cross list these courses in Science (SCI prefix); in our Systems Institute (CSA prefix), and in an associated GE program in the College of Arts (IGE prefix). Cross-listing promotes a more extensive awareness of the course by listing it in more places, thereby increasing its potential for success. Cross-listing credits both the academic units and faculty who participated in creation and continuing enhancement of the course. For example, the original ISGE Working Group was doubled in size by participation of the Fellows of the Institute for Advanced Systems Studies (IAS) and the content, design, and teaching methodologies of the courses borrowed heavily from past Institute courses and experience. Cross-listing also increases the utility and applicability of the course for students by appealing to a broader range of employers.

(2) ***Relationship with Science Departments*** **-** The ISGE Working Group has designed a program which anticipates and answers four valid concerns on the part of science departments regarding permission to offer this course series. Data indicates that it will effect less than 5 % of the total "service" FTE of the participating Science departments, therefore not threatening their health, wealth, or territory. From two to five members of their own departments will control the material of their discipline insuring its accuracy and rigor. The 150 students ISGE services would also require space and resources, so addition of the program merely redirects a small amount of existing, rather than requires new resources. Significant external funding will be sought for this unique program so it might actually add space and resources to the College of Science. Faculty who participate will be reassigned with monies equal to 0.25 Ass't Prof., Step 8 transferred to each Dept. Chair. This money is more flexible, and currently in high demand because it allows departments to buy part-time faculty for introductory, high enrollment, large-FTE-generating courses (cost less-pay more), or provide for much-needed graduate student assitantships.

(3) ***Relationship with Administration*** - The higher administration from Dean to Provost favor this program because it answers needs expressed by our recent WASC evaluation. Review of course proposals, maintenance of quality, reassignment of faculty, rerouting of faculty funding, and accountablility for supplies are best handled at the level of Dean of the College of Science.

(4) ***Relationship with Non-Science Majors*** **-** It is anticipated that only non-science, non-engineering majors would be allowed to take this series of courses. After a careful major-by-major analysis, we expect to offer the ISGE series to about 1,400 entering students of 30 non-science departments from four Colleges.In general, it appears we have to attract only one of every five students approached to join ISGE to reach our goal of 150 students per year.

(5) ***Potential for External Funding*** - The ISGE-Working Group is in active preparation of the following specific proposals for outside funding for the following anticipated amounts:

CSUC-Academic Program Improvement Seed Grant, $5000 [Awarded, Dec. '92]
Wiley Publishing Co., $30,000 (associated development of core program)[Awarded, June '92]
NSF -National Science Foundation, UG Course and Curriculum Dev't, $350,000 [in prep]
FIPSE - Fund for the Improvement of Post-Secondary Education, $50,000
NEH - National Endowment for the Humanities, $35, 000
NSF - National Science Foundation, (3 units, Education Directorate), $150,000

(6) ***Potential for Post-Graduate and Adult Training*** - We are in a time of transition in education. Training programs using multimedia technology already constitute a billion-dollar industry independent of the nation's universities and colleges. The design of ISGE anticipates future developments in these areas and adopts compatible self-study, mastery components. The CSA program plans to offer its courses through Continuing Education for a Credential. Perhaps a similar offering for these interesting and creative courses is also possible. It would also be a nicely packaged program for such new initiatives as Miller's University of the World, or for the New American Schools Development Corp. (NASDC).

(7) ***Relationship with Other CSUC Campuses*** - As a part of the argument for attracting external funding, we intend to offer the Cal-Poly ISGE program as a Model for adoption by the entire CSUC system. Since we are such a large and well-placed educational system, we have an exceptionally massive impact on the nation. The CSUC system trains 12 % of the nations teachers, and 80 % of the teachers in the largest state in the union. There are many established and proven avenues for efficient and effective replication of the Cal-Poly program on our other 19 campuses. We have collected information on four such avenues that could be used to replicate ISGE across the CSUC. The technological nature of the teaching modules, and the stability of the interdisciplinary scripts makes this program especially easy to replicate. The funding agencies mentioned above are very keen on this aspect of our program as it gives them much more impact for each dollar expended.

CURRENT STATUS OF THE I.S.G.E. PROGRAM

The proposal as described has been passed by the College of Science Curriculum Committee, the Dept. Chairs of all six Science Dept.'s, and the Dean of the College of Science for implementation in two years. It has been sent to the Faculty Senate where it was recently reported out of the General Education Committee as unanimous in support except for one abstention. We have received consultation memo's from the Dean's and curriculum committee's of the College's of Arts, Business Administration, Environmental Design, and Agriculture, as well as many of their individual departments supporting the proposed program. Two grants totaling about $35,000 have been awarded, and $395,000 of proposal monies are pending.

ANTICIPATED PRODUCTS OF THE I.S.G.E. PROGRAM AND HOW YOU COULD USE THEM

Design of this program will result in several levels of physical products that are fully replicable and transferrable to other campuses. Either the interdisciplinary scripts or the finished microcomputer multimedia modules (MMM) will be portable. We hope to publish an introductory text on Integrated Science with a systems emphasis. Pamphlets will be published on each module by a major publisher allowing other parties to assemble either a tailroed monograph on all of the integrative themes (systems concepts) for study, or tailored monographs on examples of each of the systems processes across seven sciences, or tailored monographs on examples of the twelve systems processes in a particular area of sciences. Each of these booklets could be illustrated by videodisk. It is too early to know the specifics of purchasing, borrowing, or licensing agreements, but with its extensive modularization individual items could be reassembled into targeted packages according to the needs and focus of other educators.

THIS PROGRAM DIRECTLY CONTRIBUTES TO I.S.S.S. AND SYSTEMS SCIENCE

We view this program as one of several new alternatives that seeks to expand and develop the systems sciences. Its emphasis on the natural sciences should make it rigorous and respectable. Its delivery of conventional science knowledge in a new integrative format may provide an inroad or bridge to a powerful fraternity and tradition in academia. It may attract a number of current scientists to systems science, but more importantly it may, if widely replicated, attract a significant number of students to the systems science field.

[1] *Science For All Americans: A Project 2061 Report on Literacy Goals in Science, Mathematics, &Technology*. 1989. American Association for the Advancement of Science, 1333 H Street, Washington, D.C, 217 pp.

[2] Troncale, L., 1991, "Systems Science Education at California State University, Pomona." Int. J. of General Systems **Vol.19** (No. 1): 47-69.

[3] Troncale, L., 1988, "The Systems Sciences: What Are They? Are They One, Or Many." European J. of Operational Research **Vol. 37**: 8-33.