EVOLUTION IN SCIENCE
California Dreaming
to
America Awakening

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by
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Dedicated with empathy
to those who strive for personal excellence.
Dedicated with admiration
to those who achieve it.
Dedicated with the nicest memories
to that example of excellence set by
Ray B. Potter, Physics Teacher,
Geo. Washington High School, Los Angeles,
circa late '40s and early '50's.
He provoked thinking with signs like these
hanging in his classroom:

There are very few who really think
among the thinking few.
The others don't think at all,
they only think they do.

You do what you have to do
to what you've got
to get to what you need.

TABLE OF CONTENTS

CHAPTER ONE
THE CALIFORNIA SCIENCE FRAMEWORK
PROLOGUE

INTRODUCTION

By legislative mandate, every seven years California educators prepare a Science Framework for Kindergarten through 12th grade education. The Framework is a guideline for future science teaching in California, but professional educators claim that its influence is national. Commanding the largest budget and enrollment[1], California gains a leadership position in planning simply by putting priority on curricula and text book development. The State publishes the Framework in a slick bound volume, distributing it nationwide. As the product of teachers, the drafts provide as much insight into what California education system currently teaches as the final version says of what the United States will teach in the next seven years. This California influence defines the first of three Evolutions in Science: the radiant propagation of science education, from California dream to American reality.

Throughout 1989, California framers found themselves behind schedule[2] on the latest version, struggling to absorb comments on the first field review draft. By year end, struggle had become an embroilment. A national media event ensued — the press prepared for a second Scopes trial!

The battleground was Sacramento, the State Capitol, with two forces bivouacked on the battlefield. At the extreme in

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[1]In the 1989-1990 school year, California had a public school enrollment of 4,771,978 pupils on which it spent $21.9 billion. These figures represent 11.0% and 11.8% of the nationwide totals, respectively. Sources: National Education Association, Rankings of the States, 1990; U. S. Dept. of Education, 1990; as published in the Universal Almanac, 1992

2The first release was the 1978 Science Framework. The 1984 Science Framework Addendum was a temporizing edition. The 1989 Field Review Draft Framework appeared revised and released as the 1990 edition, 12 years after the first. Distribution of the 1991 version came in March, 1991.

one camp were those with an abiding faith in science, the Pro-Scientists. They accepted every scientific pronouncement as a proclamation from on high, with the full weight of an orthodoxy. They had adopted science as a religion, with all that it speaks accepted as explanation. They were leaderless, for their Guru, Science, has no voice. If He could speak, He would be the first to admit that His knowledge is incomplete and uncertain.

Facing the Pro-Scientists were the hard core science skeptics, staffed with religious fundamentalists and commanded by Creationists. This force accepted nothing short of tangible, physical proof of any scientific claim, whether or not their religion spoke to the subject. Only a rare and strong intellect could put aside an All-Explaining Faith, ingrained in youth, to adopt stronger theories that account for the natural world. For both sides, their armor was their faith.

The State Superintendent of Education, the Board of Education, and the committee charged with writing the Framework formed a power coalition to repel the Creationists. A back room alliance decreed the Great Compromise on Evolution, making minor changes to one or two passages. The scant offering quelled the turmoil, but in the bargain provided legitimacy to some of the weakest passages of the premature Framework. It did little for science, and threatened to do more damage to a public education system already in deep distress. The problem of teaching evolution and creationism continues to reverberate in the media. This subject of biological evolution is the second of three Evolutions in Science.

In spite of its problems, the Framework is a commendable, professional work representing many man-years of effort. It has an abundance of highly quotable passages in its 182 pages — many supporting the basic ideas of this work, designed as a Strategy for Science Literacy. Much of the Framework's contribution to pedagogy, though, is beyond the scope of this Strategy.

As the work of a committee of committees, the Framework remains an uneven work. It suffers from what scientists call its boundary conditions. The calls from scientists to present an integrated approach to science went unheeded. Perhaps the task was impossible at the outset, when the State handed the charter for the Science Framework to the Science Curriculum Framework and Criteria Committee, the California Department of Education, and the Science Subject Matter Committee of the Curriculum Development and Supplemental Materials Commission! If the committees and commissions weren't enough, the bureaucracy had already partitioned curricula between science, health, mathematics, language, and social sciences. Other committees had done their work and adjourned until their next septennial feeding.

The Framework suffers, too, from technical and strategic errors. The problems within the Framework run much deeper than its treatment of evolution. This is not simply a question of good or bad biology, but strikes at the heart of the meaning and capacity of science. At the outset, the Framework lacked an over-all, structured view of science that it could apply uniformly throughout the work.

The purpose of this work is to supply that broad, harmonious foundation for science and science education. In part, it will answer the following questions. Were the passions inflamed by the Draft Framework inevitable in the conflict between religion and science? Why is there a conflict between Creationism and Science? Where does Creationism belong in the Scientific world, and why? What role should education play in the conflict between belief systems, in general, and science?

As we know what religion says about what it explains, can we ask the same question of science? That is, where does science stand on the issue of what it explains? Moreover, who can dare to speak for science? We can craft answers to these questions. In boot-strap fashion, we shall apply scientific methods to the field of science itself to dispose of many of these issues. The simple expedient of precision in the use of language helps form new definitions for science as well as evolution. It charts the course to a strategy for science. This new perspective of science is the third of three Evolutions in Science.

Dissect and perfect science as one might, in the end it will have a residual uncertainty in all its workings. It cannot supply answers with certainty; it must have a residue of doubt. An attorney in a recent trial expected an expert witness to bridge the gap between reasonable doubt and absolute certainty. Several times on national television, the examination probed along some variation of this dialogue:

> Attorney: "Can you say to a scientific certainty that this must have occurred?"
>
> Scientist: "Yes!"

Don't tell the jury, but the response may be the requisite legal answer, not it is not a scientific one. Science cannot pretend to satisfy those who need all questions answered, and answered completely and absolutely. Students can't know science knows without knowing what science *doesn't* know.

Science education in the U. S. is in a sorry state and deteriorating. The first paragraph of the Draft Framework says,

> In 1983, *A Nation at Risk* declared that American education had become victim to a "rising tide of mediocrity." The National Science Board's Commission ... confirmed that the situation in science education was particularly critical and recent studies have placed America's students last among their international counterparts in understanding science. In 1988, ... the Educational Testing Service issued The Science Report Card, and noted that ... "average science proficiency across the grades remains distressingly low." P. 1

The National Research Council reinforced these views in 1989 in the preface to *Everybody Counts*:

As science and technology have come to influence all aspects of life, from health and environment to financial affairs and national defense, so mathematics has come to be of vital importance to the educational agenda of our nation. Mathematics is the foundation of science and technology.

Increasingly, it plays a major role in determining the strength of the nation's work force. Yet, evidence all around us shows that American students are not fulfilling their potential in mathematics education.

Three of every four Americans stops studying mathematics before completing career or job prerequisites. Most students leave school without sufficient preparation in mathematics to cope with either on-the-job demands for problem-solving or college expectations for mathematical literacy. Industry, universities, and the armed forces are thus burdened by extensive and costly demands for remedial education. Our country cannot afford continuing generations of students limited by lack of mathematical power to second-class status in the society in which they live. It cannot afford to weaken its preeminent position in science and technology.

Perhaps the public is suspicious of such observations from professional educators and scientists who might have a personal stake in greater spending for education. Yet, predominantly, industry is the ultimate user of the product of our educational system. From that perspective, the critics are not exaggerating. Following the new thinking in industrial quality, the user, not the producer, of the product is the final determiner of quality. This gives authority to the view that the U. S. educational system rates an unsatisfactory mark.

Beyond this simple observation, this Strategy sidesteps the opportunity to add to the criticism. Instead, it offers new views of standard science along with a unified curriculum itself containing new purposes. The first is to develop an intuition for concepts before teaching the theory, and the second purpose is to bridge well-known mental blocks in the public's scientific literacy. While this strategy will accelerate and broaden the education of future industrial scientists, that is an ancillary advantage, a by-product of a much larger goal. A strategy for science literacy for the public is the goal, which just happens to yield a larger pool of talent for future scientists, mathematicians, and engineers.

Science training helps the mind deal with uncertainty, not just in matters of science but in life. It raises the student intellectually to the threshold of faith and beliefs. Scientific literacy is the ability to deal with our abundant technical issues — pollution, carcinogens, war and defense, drug statistics, epidemics, gambling, space, energy, water, transportation, product hazards, earthquakes, and, yes, even economics. Science training prepares the mind for understanding risk in personal decisions. It immunizes the citizen against charlatans, ideologues, propagandists, and politicians, including many with impressive scientific credentials. Literate individuals can act collectively to effect reasoned, impartial, dispassionate decisions over matters that affect the lives and well being of the world. Greater scientific literacy in the media will help build a strong school system and arrest a nation in decline. These are the reasons for studying science. Science training is the development of the left brain, sorely needed in a country all too often left-brain dead.

The ideas are not complex. What is complex is reserved for appendices. The only prerequisite for this work is an open mind and a little motivation.

THE AUDIENCE

The pragmatic philosophy offered in this Strategy for Science Literacy will help school teachers with their personal science quotient. The Strategy presents the material in a form that teachers can, with a small effort, share with their charges. The concepts should become second nature to every educator, eventually to be the standard in K-12 education. The concepts are not difficult to grasp, nor are they very controversial in the grandest of scientific schema.

The Strategy seeks also to be useful as a basic training manual in science for journalists, jurists, and the public. It will help journalists ask the right, probing and challenging questions of anyone making a scientific claim.

It will help attorneys prepare and cross-examine expert witnesses, and it could help them condition a jury to evaluate scientific or technical evidence. It will help the public avoid the charlatans and especially help them to be knowledgeable parents.

The Strategy recommends bold changes, so expect some controversy in its teachings. It will lead you through a thought process to its conclusions. As science models physical phenomena to extract the underlying patterns, so the Strategy develops its philosophy from many views and teachings. It leaves certain fringes as noise for debate, interpolation, personal choice, and correlation with other philosophies or religions. The reader can be satisfied that if he accepts what is written here, he will be able to talk with the experts. To boot, the process may lead to novel insights.

Right-brainers need not be afraid of what they will find here, nor of science education for that matter. They, too, can learn the scientific method and fundamentals. The Strategy doesn't deny that there is a place for users of both brain hemispheres, but it does challenge the sense of the exclusive-or between right brain and left brain in people.

ABOUT THE AUTHOR

Evolution in Science refers to three kinds of evolution: the biological kind, the philosophical evolution of science itself, and the geographic, radiant evolution of science education from California out to the nation. The work itself is also a natural professional evolution for a senior industrial scientist and strategic planner.

The author's academic education, reinforced by a full course of on-the-job training, is especially well-suited to the task of remedying the American science literacy problem. His engineering education began with applied physics, computers, electronics, and mathematics. Practical experience as a Naval Aviator lead to work in human factors for control of vehicles and equipment for both military and commercial applications. His 30-plus year industrial experience included design and development of a wide variety of transducers, devices that convert energy from one form to another for sensors and actuators. This provides the kind of breadth needed to attack the whole of American science literacy as a single, unified problem.

The author took his doctorate in Systems Sciences. This field is the art of mathematical modeling, generalized to all fields and disciplines, and taken to the theoretical limits. It includes the modern sciences of information. communication, and control systems theories. It provides the high level training in science needed to restructure the definition of science itself, a prerequisite to achieving national science literacy. The field also provides that systems view needed for so pervasive a problem. The systems view includes taking into account a large number of diverse factors and influences, keeping track of Cause and Effect relationships throughout complex structures, and optimizing the design of the system to meets its needs with efficiency.

Experienced as a corporate leader of Research and Development (R&D), he is practiced in the arts of basic science and transitioning it into practical products at maximum efficiency possible. This is the art of engineering development, which includes investment planning, and coordinating R&D and business planning with business opportunities. His experience with R&D and investment planning lead to strategic and business planning at all levels, from programs to corporate. This planning includes products, processes, facilities, and intellectual property. This experience in strategic planning provides an additional perspective needed for the science illiteracy problem. It provides skill in devising and structuring practical solutions, meaning solutions that work with the realities of human nature and the inertia of established institutions and bureaucracies. It provides the background needed to create policy statements that can guide primary and support organizations to the desired goals.

The author's duties included training a full complement of professionals, from scientists, engineers, program managers, and technicians, to administrative people, including finance specialists. He retrained the weak product of the American educational system, and cross-trained between disciplines, including especially basic science, engineering, and finance. His experience as a counselor for scholarship and fellowship student/employees, and for women in engineering provide special insight into the education and literacy problems today.

In the last decade, he performed liaison duties with Universities in several capacities, including: Cochairman, UCI Science Education Advisory Board, a widely recognized program that helps prepare high school students for University education. Lecturer on modern technology and on the economic impact of the defense industry. Lecturer in the UCI Summer Math Institute for secondary school teachers. His subjects included applications of high school algebra in industry and teaching probability theory. Previously, lecturer at UCLA in advanced engineering short courses. Memberships include: Academic planning committees for the UCI School of Engineering and for the Department of Electrical and Computer Engineering. Ad hoc UCI Extension Dean Selection Committee. Science Advisory Board, Orange County Discovery Museum. Corporate mentor, Women in Engineering Program, California State University Northridge. Today he is a consultant in engineering and strategic planning and a writer in technical, political and economic subjects.

This professional background, plus seeing two children through public school and university systems, helped him develop a pragmatic view of science. Shortly before entering private practice, his employer assigned him the job of critiquing the Draft of the California Science Framework for the State Board of Education. He shares these experiences in the *Evolution in Science* with teachers, administrators, text book authors, and parents. His first objective is to see high school graduates prepared for the Real World and for the more rigorous college curricula. A secondary goal is to provide a reference work in science and technology literacy for journalists, jurists, politicians, and the public at large.

IN CASE OF ERROR

If you find an error in this work, the author would appreciate hearing from you. He reserves the right, however, to reject any conclusion that because of one or two basic errors, the whole work is discredited. He is a system engineer, trained in the process of perfecting a work through iteration.

This is reminiscent of an old joke:

> Patty struts into a pub, and proudly announces, "Oy can lick any man whose name's on me list!"
>
> To which a deep voice rings out from the back, "You tink you can lick me, do you?"
>
> "And what might your name be?" says Patty.
>
> "Mike O'Toole, hisselfl" answers Deep Voice.
>
> "Here i' tis! Number forty one on me list."
>
> Mike, a giant of a man, rises to his full height and width, growling: "Why, you little pip-squeak! You can't lick me!"
>
> Patty, touching his pencil point to his tongue, says, "OK. Oi'll take your name off me list!"

Patty was a system engineer.

So if the author agrees with you on a correction or a clarification, he'll fix it in case there is a reprinting!

CHAPTER ONE
THE CALIFORNIA SCIENCE FRAMEWORK
BIOLOGICAL EVOLUTION

INTRODUCTION

Strife over the drafting of the California Science Framework was unnecessary. The framers brought the problem down on themselves. They flagged the bull, making the Creationists see red, as it were. They exalted and defended the Theory of Evolution to the point of unfounded, undeserved, unscientific excesses. This had the triple-barreled effect of inflaming a sensitive public issue, weakening the science in need of reinforcement, and isolating members of the community who might have defended the Framework. Most of this treatment survived the Draft to become part the final 1990 edition.

Here is a sample for Grades 6-9:

> Evolution, defined as "Descent with Modification," is the central organizing principle in life science. F90-p. 133

Earlier in the introduction and discussion of themes, the Framework obstinately refuses to give students and Creationists a working definition of evolution.

> Evolution in a general sense can be described as change through time, and virtually all natural entities and systems change through time. But evolution is not just the history of natural things; it is also the study of patterns and processes that shape these histories. F90-p. 29

Moreover, it modifies the definition given for 6th graders:

> Evolution, which Darwin described as "Descent with Modification," is ...F90-p. 29

Charles Robert Darwin authored the term "Descent with Modification" around 1858, when Christian teachings on creation had to be the foundation for all contemporary Western work. This was a time when failure to acknowledge divine origins in one's writings meant personal and professional ostracism, if not worse.

Descent with Modification may be the weakest definition imaginable for evolution. It does extract the essence of Darwin's departure from traditional teaching. Yet it does little more than imply that either species have changed since a time of creation, or that creation is a process — that it did not occur all at once. At this level of definition, evolution is difficult to recognize as a scientific model or theory. It is but the recognition of the existence of a natural process.

Nonetheless, Descent with Modification is something less than an obvious process to a casual observer. Its demonstration is much more difficult than gravity or electricity. Still, the supporting evidence for the changing of species is overwhelming. It is close to a certainty, in part because science has no viable, objective alternative. The Strategy will ask that it be much closer to a certainty, however, to earn the status of a fact!

The Draft Framework had a sidebar[1] commentary for Grades 9-12:

> Evolution is both a pattern and a process. It is also both a fact and a theory, like gravity and electricity, that explains a large range of observations and hypotheses about the natural world. ... As more detailed understanding increases, the theory of evolution itself evolves. DF89-p. 105[2]

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[1]The Draft contained pedagogical sidebars throughout, much as found in this strategy. The preface to the final edition mentions this feature, but the sidebars appear to have become extinct.

[2]Criticizing a draft document is generally unprofessional. It is indeed bad form, and not a very smart practice. This work, for example, undoubtedly contained stupid and embarrassing remarks in some of its draft forms distributed for peer group and editorial review. No author would want to invite a public lashing over errors in a tentative document. The Draft Framework was, however, the subject of the great debate in Sacramento between creationists and science educators, and no official has revealed the specific compromises made in the Framework to accommodate the creationists. Also, the Framework is the product of committees, not an individual. It acknowledges contributing writers separate from the drafting committee. Like the Framework itself, it is the work of professional educators, supported by scientists and consultants,

Fact, as most English words, has many shades of meaning, but it is a candidate for the strongest word in science. Primary dictionary definitions cast a fact as something known with certainty. Science claims nothing with certainty. In science, a fact is a datum — an observation measured within a well-characterized accuracy. Webster's[3] says a fact is

> "an actual happening in time or space <fact in its primary meaning, as an object of direct experience, is distinguished from truth>."

A measurement is the scientific process that establishes a fact. A model does not. Moreover, Science does not deal with truth, but with models of the Real World. Still, a fact must be understood in context. A sign of the Zodiac is a fact in a scientific study of astrology. Uniformitarianism is a fact in an objective discussion of the field of geology, for the principle is demonstrably used in the field of study. Neither the Zodiac or Uniformitarianism is a fact within their respective fields.

As Descent with Modification is indeed the foundation of modern biology and the basis of many competing theories of evolution, it is a *principle*, a term that the Strategy will come to define. Where man has observed and measured this evolutionary process, little doubt remains as to its factual nature. When physicists define gravity as the mutual attraction of masses, it has a similar factual basis. When gravity is Newton's action at a distance, it becomes a law — science's highest ranking for a model. Its validation is firm, and its utility is immense. Still, Newton's model has unsettling attributes. It troubled his contemporaries, and it

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which had at least the opportunity for a substantial degree of internal peer group review. With apologies to the individual framers, the Draft is quoted only where it may illustrate the process of compromise, demonstrate a change of thinking, reinforce an error not eliminated by the final editing, or contain the last available reference to an important idea.

3*Webster's Third New International Dictionary*, Encyclopaedia Britannica, 1981 motivated Einstein to theorizing about relativity. It continues to prompt new investigations and modeling.

Darwin didn't use the word evolution, but he did describe a theory significantly larger than Descent with Modification. His model included natural selection and gradualism, the concept that the process worked over vast spans of time. This was perhaps the first Theory of Evolution. Darwin chose his words with the care of a scientist, documenting his work with extraordinary thoroughness. Still, simply no evolutionary theory including Darwin's is fact.

To be generous, the Framework's treatment of evolution is consistent with popular biology textbooks. One could wish that both the Framework and modern text books were as careful with their language as was Darwin. Once an educational document defines a word, it should restrict its usage to that definition. A common practice in technical literature is to permit different definitions within a work, but with a disclaimer like "the meaning will be clear by the context." The two meanings of *objective*[4] in the following sentence are clear form the context:

> The objective of science is to predict from objective models.

In this instance of a governing document for education and in view of the sensitivity of evolution as an issue, the tolerance for ambiguity is quite high. The Framework, like the biology texts that preceded it, encourages an association of

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[4]*Objective* is overburdened, having at least four or five principal meanings both as an adjective and as a noun. The Strategy uses it repeatedly in just two ways. As a noun, it is used as a target, as in a goal or mission. As an adjective, it is used in the sense of existing independent of the mind. The Strategy defines each use in detail. As an adjective, the Strategy never uses it in common sense of fairness, honesty or balance. It is never used in the grammatical sense. The Strategy makes the strongest distinction between objective in the sense of perceptible to the senses, using objective in the sense of relating to the world external to the senses.

alternative definitions of evolution with the attribution *fact*. Among the few and vague evolutionary models, only Descent with Modification warrants the name *fact*. More elaborate definitions of evolution rank as low order models that divide biologists. Darwin gradualists subscribe to a form of *Uniformitarianism*[5]. *Punctuationalists*[6] put more emphasis on abrupt changes and species selection over individual selection. They include Adaptive Evolutionists, discussed more completely below.

Names like *phenetics*[7] and *cladistics*[8] identify different schools of evolutionary theory, organized along taxonomic lines. They reflect different organizing mechanisms, which produce highly conjectural results.

Evolutionary theory includes models of different scales, known under the names of *microevolution* and *macroevolution*. Each has its own degrees of sensitivity to environmental changes. Each accounts differently for the effects and causes of mass extinctions and for the appearance of gaps in the fossil records. They include subtheories like genetic drift, the bottleneck effect, and the founder effect. Today the models are undergoing rapid change as the young field of molecular biology opens entirely new lines of investigation.

In short, the development of any kind of unified Theory of Evolution is in an early state. The theory is in scientific turmoil. It is a fascinating, robust, dynamic field, with room for a few more PhD biologists. It embodies physical sciences,

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[5]Uniformitarianism is the principle that natural laws hold at other times and places. A detailed discussion appears later in the chapter.

[6]Advocates of punctuated equilibrium, a subtheory of evolution in which change occurs rapidly in brief periods.

[7]A taxonomic principle based on traits expressed characteristics of a life form, as distinct from its genetic composition.

[8]A taxonomic principle based on the time at which a life form arises along a branch.

mathematics, and earth sciences. It is a fertile field for the budding scientist to plow.

Yet, the 1990 Framework says,

> Evolution is more than simple change because it is change with a direction: that direction is time. Through time, life has evolved from simple forms into the present array of organisms on earth. F90-p. 29

The sense of this paragraph is not clear. The words *evolution, change, process*, and *time* can be difficult to separate. Since basic processes involve time and no one has experienced anything but unidirectional, constant time, what particular insight is the author trying to share? These statements begin the Framework's fogging of the concept of evolution.

Most processes involve time as an independent parameter. However, Science generalizes the notion of process to include changes that occur over spatial coordinates, and educators should develop both concepts as a part of a theme of Systems. Evolution is an excellent pedagogical example because it exhibits directions in both time and spatial coordinates. Evidence comes from the variations found in plants and animals across geographical loci in steady state. For example, some plants exhibit different forms at different altitudes on the side of a mountain. This is what the Galapagos meant to Darwin.

The Framework continues:

> Within evolution there are some recurring subthemes that can be woven into instructional curricula. One such subtheme is direction, and, as noted earlier in the treatment of evolution, time provides the direction to evolution. In most natural systems, what happens next depends to a large extent on what has happened before. In ecosystems, succession of a biome is more likely to have a predictable direction based on previous successional stages of the biome than it is to be random, because one successional community sets the stage for the next. The evolution of life on earth has been facilitated by the evolution of the atmosphere, which

> the organisms on earth have changed substantially through time. This has been an interactive process. ...
> F90-p. 30

The statement about succession in ecosystems is highly subjective. What does the cliché "sets the stage" mean? What does the author mean by "predictable direction"? By an earlier definition, time is that direction, now time provides the direction. Could the Framework be declaring that succession in ecosystems somehow has a predictable time? The part that is subjective and objectionable is the degree to which one sees repeatability in the succession. To the racist's eye, all members of a species might be indistinguishable. Certainly a litter from a pig is not too likely to contain a horse, a protozoa, and something that looks like a tomato.

Characteristics of species are statistical measures, as in the average features of a population or various measures of the deviations from averages. Indeed, a species is an aggregate, or statistical concept. Until DNA typing is a little more advanced, a species changes when its statistical measures change. Populations exhibit a direction in their statistics yet individuals in the population are born with measurable, and significant random components[9]. That the litter is going to resemble mostly pigs is a weak, predictable direction. But the contributions of genetic material from the sow and the boar are random to the best of anyone's knowledge today. Mendel believed they were random. Since Mendel's time, discoveries have compounded biological knowledge at a dazzling rate, unifying the model of life on all levels. At the same time, the discoveries have increased the list of random contributors to life's processes. Perhaps every step in reproduction can have a random outcome, some considered normal and others known as mutations.

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[9]The height of the human species by race is most instructive in terms of trends and variations. An exercise for students is to survey the heights of young adults in their families compared to their parents, and to look for trends.

The Framework sends a message that the writer is struggling with a feeling of discomfort with randomness in general, and with randomness in evolution in particular. Neither is appropriate for a well-trained scientist. The Framework says,

> A third subtheme [to evolution] is that of chance. The randomness of Brownian movement[10], genetic mutations, the Heisenberg uncertainty principle[11], and the toss of coins are familiar concepts in science curricula. Chance has played an important role in the development of molecules, structures, and societies because it presents natural variation in what is possible. Of course, each case is determined by specific factors and is anything but random. F90-p. 30

Randomness and chance are not as the Framework suggests occasional happenings in the Real World. Everything known in science is represented in a model, based on measurements. Every measurement has a limitation on accuracy, and so the models must as well. No model for evolution, even with the advantages of all that has been learned, would be capable of predicting the emergence in history of the mammals. Nor can any model predict the appearance of canines. Nor of Dalmatians. Nor of any specific pattern for the spots on any Dalmatian. These models representing different scales of resolution might someday be integrated into a larger, more comprehensive and all inclusive model for evolution. This model, in turn, must have residual errors. It may be superior at every scale to anything available today, but if the history of science can guide us, the new integrated model will have even more parameters about which it will have uncertainty. The chances for a biologist to create such model will be greater if

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[10]Brownian movement is the random movement of particles suspended in a liquid or a gas due to molecular collisions. Einstein showed that the effect is due to temperature.

[11]A principle of quantum mechanics stating that the product of the measured errors in two related parameters has a lower limit. Heisenberg won the Nobel prize for his creation of the quantum mechanics.

the education system teaches students how to cope with uncertainty.

Perhaps the problem is widespread among biology educators. The college text, *Biology* , attributes the following without comment to Ernst Mayr, a Harvard biologist:

> Survival in the struggle for existence is not random, but depends in part on the hereditary constitution of the surviving individuals. Those individuals whose inherited characteristics fit them best to their environment are likely to leave more offspring than less fit individuals. C90-p. 431

Usually one must make allowances for different terminology from field to field. Random may mean in some applications complete unpredictability in some sense. This is not so in mathematics, which is the language of all science. Precision in science has no room for such a generous interpretation of random just for biology. Conversely, the use of the word *likely* is consistent with the accepted meaning of randomness and chance. The denial of random in the first sentence above is put to the lie by the word *likely* in the second.

To Mayr's observation, the text *Biology* adds,

> Variations arise by chance mechanisms ..., but natural selection is *not* a chance phenomenon.

In another place, the Framework is comfortable with randomness and spatial variation of the species when it says,

> Chance factors important in the history of life include the unpredictable effects of genetic recombination, the restructuring of the genome[12], and the migration of new individuals in and out of a population and of populations into new areas. On a larger scale, the introduction of predators or competitors, long-term and short-term changes in climate, and environmental catastrophes are all chance factors that shape the history of the Earth and its life. F90-p. 30

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[12]The complete genetic complement of a life form.

In the end, man and science must have a residual uncertainty and randomness in all things. The Strategy discusses these topics further in Chapter 7 in dealing with the inevitable boundary between science and the Real World.

Succession in the species is one of the phenomena of the Real World for scientific modeling. A model in essence is an extraction of a direction or pattern from the phenomenon. The model will not be perfect, and scientists will challenge every random component in it. They will successively replace more and more of the randomness, advancing new models in the process. Those random components are a pointer to research problems for the University and industry.

Models embody the essence of objective knowledge. The Framework misrepresents models and their importance in its discussion of the theme Systems and Interactions:

> To study systems, we generally focus on one or a few aspects of interactions at a time to avoid an overload of information. These interactions are commonly described in simplified terms as models. Models almost never simulate all the factors that are interacting, nor all the ways in which the factors interact, but they do provide a way of describing natural phenomena that are organized in systems. F90-p. 33.

Nor are models simply physical mockups that illustrate a point or approximate nature. The following is objectionable

> Students should be introduced to the concept of the use of models in science by such exercises as constructing molecules from toothpicks and candies or bolts with nuts and washers ... F90-p. 50

because it associates models with the simplistic idea of physical assemblies that look like or act like some part of the Real World. All of the language and mathematics of science are but models, representations of the Real World. The Framework implies instead that science contains somewhere a greater understanding or appreciation of the Real World, which models of a certain type approximate. Any phenomenon is likely to have multiple models at different scales or resolutions (to avoid information overload), but science can model no phenomenon completely. The fact that a model can grow to the point of information overload is a human limitation, not a bound on science! Extreme complexity is the puniness of man's intellect from a different perspective. Science has no concept of the Real World other than its models.

Another critically important concept here is the role of repetition — from repetition in forming basic observations, to repetition or iteration in detailed scientific modeling. What a human is capable of observing depends upon the training of the brain, from the stimulation of colorful objects hung over the crib to the training received as a scientist. To eliminate the subjective in these observations and to share and enlarge the observed world with others, scientists make measurements of the observations. What they model are phenomena based on those measurements. They design the models to have predictive value, reflecting the patterns that they extracted from the description of nature.

Saying that "succession ... is ... likely to have a predictable direction" is subjective; it is not consistent with the meaning of science. It suggests that the next evolutionary step, whether it be a new species or a new variety, is predictable. Nothing could be further from the state-of-the-art of modern biology. A biologist presented with a single new specimen cannot in general even say whether it represents a new species, a variant, a hybrid, or a mutant.

Scientists find patterns in the observations, patterns of change and patterns of constancy. Some patterns of change biology calls evolution. If man could stand back and observe the development of life on earth in compressed time, like a video tape on fast forward viewing, change would be the most obvious and fascinating attribute of the scene. To a large extent, what the framer cited as the constancy in succession is but the brevity of a human life in the grand unfolding of the natural world. The Framework applies a principle of inertia to evolution. Instead, the duration of a phenomena is to the history of scientific thinking as its complexity is to our intellectual capacity.

Randomness has long been the subject of philosophical debate. Some would deny its existence in nature, but to do so would deny entropy, the measure of disorder or randomness. A principle in science is that every Effect had a Cause, and the scientist searches backward along an infinite series of Causes and Effects. However far back the state of knowledge has progressed in the chain, the preceding Causes are simply chalked up to randomness. Random, though, does not mean unpredictable in every regard. Science teaching cannot let random mean the state of maximum entropy for biology when it has a distinctly different meaning in mathematics and other sciences.

For example, consider the pigmentation in a litter of puppies, or in a sequence of litters from the same parents. The puppies still have all the predictable characteristics of their biological structure down to the breed, and even the finer detail of their particular pedigree. Still, they possess random characteristics like pigmentation as far as anyone knows. They contain even more subtle variations that breeders exploit to create altogether new breeds. In the Framework's successional community, the puppies' parents "set the stage" for the litter, and the dogs "set the stage" for the new breed.

The essence of change, whether for the breeder or for evolution, lies in the random components. Many random processes have a bias, nonetheless they are random. Natural selection *is* a random process, a chance phenomenon.

By its poor treatment of the directions or patterns in evolution, the Framework leaves the impression that Descent with Change, or evolution, is a pre-determined or even proclaimed pattern creating ever more complex species. This suggests an intent to evolution or the existence of a determiner or ordainer. Science has established neither conjecture, nor does it have the first supporting fact on which to base such a hypothesis.

The preceding criticism is supported by the Framework in the following quote, which just might be wrong!

> ... it is misleading to portray evolutionary history as a drive toward increasing complexity. F90-p. 132

If the operative word is *drive*, then the only fault with the sentence is its clarity. The problem arises if the operative phrase is *toward increasing complexity*. The trend of Descent with Modification clearly is in the direction of more complex forms on all scales.

In the next quote, the Framework has a problem with logical inference:

> Through geologic time, adaptation to environmental factors has been a central theme in the evolution of life. F90-p. 135

What would have happened if life had not adapted to environmental factors? It simply would not exist; it would not have survived any changes. Because adaptability implies survival, one cannot deduce adaptability from survival[13].

In several ways, the next quote demonstrates a problem with Cause & Effect in evolution:

> Not all evolution is adaptive, and organisms cannot simply invent the characteristics that would serve them well in particular circumstances. Evolution is limited by the possibilities for genetic and behavioral change because organisms can use only the genetic and structural tools handed down by their ancestors. Even so, living things have great potential to be modified by natural selection to meet environmental needs (e.g., the evolution of beak shapes in the small group of Darwin's finches). F90-p. 135

Should one infer from the first two sentences that organisms willfully use the "tools handed down" to them to effect an adaptation? Is this auto-genetic engineering? Likely the author did not intend that meaning, but the issue of evolution

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[13] $A \rightarrow S, S \therefore A$ is not a valid argument.

and the Supreme Architect is far too sensitive for anything but precision.

In the third sentence, the expression "modified by natural selection to meet environmental needs" suggests that the environment applies a pressure or perhaps triggers a response in the organism to adapt to a specific environmental condition. Such a process requires that genetic material have the ability to sense either the pressure or action, and somehow detect the condition to which it must adapt. For example, suppose the climate were to change suddenly to colder and drier. How would an organism know that this was a climate change and not a temporary weather anomaly? How might the organism know to adapt to colder and drier and not, say, modify for hotter and wetter? This scenario is quite improbable; it requires too many assumptions for a scientific model. The Strategy shall propose an alternative model with far fewer assumptions.

Darwin chose his words with care. The operative word in his theory is *selection*, not *change*. The environment does not create a change in organisms. In an entirely passive way, it is a selecting agent among what science must first regard as spontaneous changes. Natural selection causes variations about the way that a cookie cutter causes cookies.

CHILDREN OF THE ATMOSPHERE

Saying in the quotation cited above that the evolution of life "has been facilitated by the evolution of the atmosphere," the Framework makes two basic errors. First, it uses the word evolution in two different senses, creating a false analogy. By the dictionary, evolution has a variety of meanings that amply cover the two uses here. At one point, though, the Framework defined evolution for the reader as Darwin's 'Descent with modification. This definition is quite inappropriate as an observation on the atmosphere, implying as it does that atmospheres have descendants.

Still, the relationship between the atmosphere and evolution is vital to science. The spread of life on earth altered the atmosphere, and the changed atmosphere comprised new niches to which life adapted. The atmosphere continues to change, influenced by the sun, the ocean, volcanoes, continental shifts, life, fires, storms, and industry. No climate model today can predict where the atmosphere is going, nor which parameters act to give the atmosphere its remarkable stability in composition and temperature. No scientist can determine whether or not today's changes in weather signal a change in climate. Some scientist will someday be create a model of the atmosphere that can be validated. This model will allow him to predict what catastrophe might befall the atmosphere and man, and perhaps prevent it. The changes of having that kind of scientist will improve in proportion to nation's science literacy.

The second problem with the citation above lies with the word *facilitated,* which means that a task became easier. An implication of this word is that the evolution of life has a task, or a mission. This giving of a will to evolution is not acceptable science, and is fundamental to the criticism of evolution in the Framework. Indeed, it carries with it the implication that science is in and of itself a religion.

Sometimes science gets close to assigning a will to a phenomenon. The method allows science to come no closer than establishing a principle. In scientific discourse, principles are frequently tacit. This may be universally true of Cause & Effect. Scientists must not invoke other principles so casually. For example, the uniformitarian principle presumes a pattern not in evidence! Principles are generally not demonstrable, for if they were scientists would advance them as models to become laws. Like all basic tools of science, they are manmade and not unique. Science has no way to establish that the atmosphere was a lucky or planned development that allowed evolution to proceed on its destined course. Nor can science determine that any of the forms of electromagnetic radiation that cause mutations are somehow in synchronism with an independent plan for evolution. If the evolution of life and atmospheric changes occurred in synchronism, what was the coordinating force, the Cause? What was the shepherding satellite? Any such hypothesis implies either that evolution was a pent-up energy with a direction of release, a vector metered by changes in the atmosphere, or that a Shepherd or Planner intervened to coordinate the different processes.

The argument is persuasive that the atmosphere did not so much *facilitate* evolution of life as that it was one of the selecting forces which *permitted* the evolution of life to follow some random path. It is much like a rock that falls into a river, changing its course to the sea. Life changes so as to be adaptable to short term changes in the environment, for otherwise life would not have succeeded at all. A species changes so as to be efficient when it happens upon a niche, for it is in competition with other variants for resources.

EVOLUTION EXERTS A FORCE TO BETTER STATES

The Framework speaks sometimes of a direction to evolution and at other times of evolution from simpler forms. This language has the sense of assigning a purpose to evolution, an implication of a preferred path. The Framework casts evolution as an independent, elementary force or energy, one with a will, guiding the development of life on Earth. In this sense, evolution has a mystical, religious power to it. Yet many scientists, perhaps most, would sat that evolution is merely the history of the development of organisms. The power implied is certainly not within the meaning of Descent with Modification.

In treating evolution as a force, the Framework gives to evolution the power to explain, rather than simply being a generalization of the observations. Evolution taken as a force implies a guiding hand. That Guiding Hand might be Evolution itself, or a Higher Being. Science is at a loss to determine the Family Tree, for it cannot establish even the basic premise of the Framework. Evolution is science, not a new religion. Yet a wise religion might encompass and accommodate evolution.

Absent the Framework, one might believe that the controversy between Creationism and evolution was one-sided, coming from the fundamentalists. The Framework gives the impression that science is pressing the issue as well! An excessive preoccupation with the power of evolution is an unscientific and inflammatory reaction to the Creationists.

Treating evolution in any sense as a direction toward better states is equally objectionable to saying that it contains a predetermined direction. Better states again implies a guiding force and perhaps human-like judgment. Do not construe this as an argument against the Guiding Hand, but only that the Guiding Hand implies a quality judgment unavailable to science. Lacking measurements to the contrary, science cannot evolve such a model and therefore must remain secular. Critical aspects of the controversy are both whether or not man had non-human progenitors, and whether his development represents a general trend toward better states. The only scientific model available, namely evolution, must include the development of today's human forms.

While certainly most scientists must believe that the human is the superior life-form on earth, science can have no such value or belief. Science measures the intellect of man and the animals, and the results show that man bests the others. Science measures the progress of man and the domination of the planet by him. It can determine quantitatively that no other animal has begun to have such effects. Scientists can hypothesize criteria and measure the positions of species on an unlimited variety of multidimensional scales.

Still, the scientific process has no procedure to rank these criteria. To declare that any state in any process is better requires a reference to an external, subjective value system. For example, suppose man manages to destroy the planet, as some fantasize he might. Was he then a superior species? Suppose a natural disaster like the one hypothesized to have wiped out the dinosaurs overtakes the planet, this time destroying only the mammals. Weren't the ants then "better" than man? Even today we have humans who think that science could rank the races of humans. And to animal rights advocates, herbivores outrank carnivores. Perhaps this sense of evolution to superior life forms is behind some of the feeling of environmentalists that today's species are robust survivors, destined to last forever — that extinction of a species must be the result of unconscionable acts of man, the Despoiler of the Planet.

Putting the issue of man aside, science cannot declare that modern species of any life form are superior to any earlier form. Apparently the newer have adapted better to their environment, where the criterion is mere existence. However, some modern species undoubtedly became over-specialized, losing much of their adaptability. Suppose that a species somewhere is so delicately adapted or so dependent on other life forms that a minute change to its habitat would doom it to extinction. This hypothetical life form has evolved into a corner in the house of the environment. Perhaps the slow-moving koala bear with his dependence on one species of eucalyptus trees is an example. Is this creature better in some sense?

Science does not say that man is the terminus of the evolutionary trail. Based on the evidence, evolution may be continuing today. Other life forms continue to evolve, and some might out-perform man in many regards. One component of superiority might be duration, which is measurable. In this dimension, mammals have a long way to go to catch up with the record set by the dinosaurs (60 million vs. 160 million years), or even the lowly cockroach!

EVOLUTION AS A THEORY

Evolution is a strong theory, irreplaceable in biology when viewed as a generalization of the history of change. It stands on its own and educators need not exalt it. The Framework simply overplays the pivotal theory of evolution. Indeed, evolution is as important as any subject in school! However, it remains a theory, though not in the sense the framer's use that word. The Framework's general defensiveness about scientific theories overplays their strength in scientific matters. In this way, the Framework introduces semantic difficulties, especially with the key words *fact*, *theory*, *principle*, *observation*, *hypotheses*, and *explain*.

A motive for the Framework's excesses is understandable, but the result is unfortunate. No student is going to make much progress in biological science if he cannot put aside beliefs in the immutability of life. The student might be able to think in two modes, one scientific and one theological, but more likely a strict holding with the Creationist belief is likely to face an insurmountable mental obstacle to learning biology. By resorting to excesses in biology, however, the Framework damages science education on a much broader front.

The Framework cannot rely on biology text books and curricula for authority. These works suffer as does the Framework with traditional, subjective models found in many disciplines, and a certain casualness with the language. Instead, the Framework needs to lead the educational community in new, firmly scientific directions.

Students need solid answers to basic questions like

> How strong is a scientific theory?
> How is it that theories contain laws, as
> > Mendelian laws in genetics
> > the laws of probability in Probability Theory?
>
> What does a principle entail in science?
> What does it mean for a science to explain?

Clearly evolution does not explain the development of life on earth to the Creationists.

EVOLUTION VS. CLASSIFICATION

The Framework says,

> Classification is based on evolutionary relationships, not on any arbitrary criteria or on vague notions of similarity. F90-p. 133

and again,

> ... it is still essential to show that classification of living things is based on evolution, because evolution explains

> both the similarities among living things and the diverse paths taken by different groups through geologic time. F90-p. 116

This is convoluted. Instead of deriving evolution from the data, the Framework has science presuming the fact of evolution. Biologists create a model from the data, inferring relationships. They classify according to homological relationships, and call the result evolution. To say that classification is based on evolution reverses the order. It makes classification depend upon the consequences of classification.

Biologists often face difficult decisions in constructing the taxonomy of life. In the end, some classifications will be arbitrary or weak, and one cannot find much fault with a decision that is more supportive of evolution. Such a decision becomes a confirming datum for evolution, because it is construable in a manner consistent with the evolutionary model. This process taints the classification, however, denying its use as a point of *validation* for evolution.

The distinction is critical to scientific thinking. Students will benefit from examples. Science does not permit itself to sort data selectively according to the theory that they support. Any break with this dictum moves the arena of discovery into social sciences or pseudosciences. These concepts of supporting data, of confirmation and validation, are part of the Scientific Method, discussed in detail in Chapter 6.

COMMON GENES VS. COMMON ANCESTOR

The Framework declares that homologous relations are the consequence of a common ancestor:

> Some tissues and organ systems, as well as biochemical molecules, are homologous within large groups because they are inherited from a common ancestor. F90-p. 120

The logical relationship appears in the diagram at the top of the next page. This may be a reasonable inference, though far from a certainty. Biologists might expect to find similarities passed down from a common ancestor because of the known workings of inheritance. If the inference were true, then the

$$\boxed{\text{COMMON ANCESTOR}} \longrightarrow \boxed{\text{HOMOLOGOUS SYSTEMS \& MOLECULES}}$$

COMMON ANCESTOR IMPLICATION
Figure 1-1

absence of homologous systems and molecules would mean the absence of a common ancestor. However, the inference is not certain and indeed homologous systems and molecules exist in nature.

Does the reverse relationship hold?

$$\boxed{\text{HOMOLOGOUS SYSTEMS \& MOLECULES}} \xrightarrow{?} \boxed{\text{COMMON ANCESTOR}}$$

HOMOLOGOUS SYSTEMS IMPLICATION
Figure 1-2

The Framework authors believe that it does:

> All living things have a homologous genetic material, represented by RNA and DNA ... . This feature demonstrates the unity of living things and their evolution from a common source. F90-p. 118

and

> Life is considered to have had a single origin (to be a "natural" evolutionary group) because all living things have the same genetic material (RNA or DNA). F90-p. 123

"Life is considered" only hides "scientists believe", which the Framework decries, in the passive voice that editors decry. More importantly, how does the conclusion follow from the premise? Is this a law, a theory, a hypothesis, or a conjecture? Actually, it is a phantom model.

Why might it be more probable that life originated just once? Why couldn't a process exist now or at some earlier time that would create common or similar RNA and DNA spontaneously in more than one place and time? People like to imagine that because the universe is so vast, life is likely to exist somewhere else. Why not twice here, at some other time or place? This, in fact, is one of the great unanswered questions in biology that would make a sample of extraterrestrial life so valuable.

Suppose a biologist found several molecules in nature like DNA, call them ANA, BNA, and CNA. Then he might sort life forms into the four types and conclude (or conjecture or speculate) that each derives from one of four different ancestors. Would he speculate that ANA and DNA, say, shared a common ancestor? Perhaps, but having trained in the Scientific Method, he would seek more evidence. How do ANA and DNA differ? Suppose now that ANA and DNA exist in nature, but biologists haven't learned to recognize the differences at this level of detail! Then this hypothesis might prove to be true. That is, we may conclude that all life had a common ancestor simply because we lack the resolution to discriminate among DNA-like molecules. Could a biologist mix up a stew of the ACGT nucleotides and create an independent ANA molecule, in a manner analogous to the Miller-Urey experiment? If he did this, would molecules by definition be DNA? This strikes at the heart of DNA definition.

The circuitous construction in these Framework passages is lacking in Cause & Effect. It is symptomatic of a chronic problem with logic in the document.

CREATIONISM IS NOT SCIENCE

Science educators need to devote class time to providing a constructive critique of Creationism and the pseudo-sciences, showing why they are not science. This should be done with some degree of equanimity. The idea is for the student to learn what science is and what it is not, not that science is either superior or inferior to their traditional values or any religion.

The Framework needs to help in this pursuit. It should take advantage of its keystone position in education to state specifically and respectfully why astrology, parapsychology, religion, and Creationism fail to qualify as science. No superiority could be claimed for science, even if the other fields fail to reciprocate! Such a determination is a subjective and valid judgment for each individual to make, and is outside the realm of science. Such a treatment would serve as an example for teachers, and it should relieve any pressure to defend evolution with such intensity.

Part of the conflict stems from the semantic problem with the word *explain* or *explanation*. All but one of the standard dictionary definitions of *explain* contains a strong subjective component, an inference of human satisfaction. The notable exception is the definition in the sense of accounting for, meaning to show simply the connections between known conditions. This is a rather mechanical definition, absent any sense of quality or judgment. In its subjective senses, whether or not science *explains* something depends upon the perspectives of the listener. Science cannot explain in these latter senses because the definition restricts science to the objective world by definition. Science can account for the Real World in the more mechanical sense. Science is a secular game like logic and mathematics, governed by rules and assumptions. Anyone, believer or nonbeliever, can play the game.

For example, Newton discovered that God appears to have put a pattern in gravity. It appears to depend on the product of the masses, a property of the modern-day model for matter that Newton created and named. The scientific question was secular and objective — on what does gravitational attraction appear to depend in experiments that can be made by any reasonable person? Science leaves to theologians and philosophers the question of whether or not the appearance is a consequence of Chance, of gods, or of God.

Meanwhile, what is the apparent pattern in the workings of gravity? Whether or not these Real World attractions were created by none, one, or many Makers, locally or universally, are theological matters. Science analyses the natural world according to the rules of the game, accepting the evidence as perhaps He created it and looking for patterns in His data. Science accounts for the Real World for the believer if he accepts the Scientific Method and follows it religiously.

The Framework is the logical next step and place to effect the Policy on the Teaching of Natural Sciences[14]:

> If a student should raise a question in a natural science class that the teacher determines is outside the domain of science, the teacher should treat the question with respect. The teacher should explain why the question is outside the domain of natural science and encourage the student to discuss the question further with his or her family and clergy.

The Framework responds to this policy with,

> The teacher is ethically and professionally bound to confine science instruction to the facts, hypotheses, and theories of science. F90-p. 25

This is patent nonsense! In what way are the ethics and professionalism of teachers violated by the teaching of, say, science ethics? Where is the student supposed to get an objective treatment of pseudo-sciences and the excesses of people claiming to be scientists? Teachers need to discuss controversies relative to science, pointing out scientists' concerns. Scientists have conflicts, disagreements, and unknowns, and always will have. Usually they resolve their conflicts, and science moves on. Science is not nearly so deterministic as the Framework wishes. Open discussions of this sort help cast scientists in a more human light. Moreover this kind of controversy is most stimulating — it keeps students awake and encourages them to pursue careers in science.

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[14]California State Board of Education, "Policy on the Teaching of Natural Science", January, 1989

What is the teacher supposed to say when the student asks, "Why is creation outside the domain of natural science?" or "Why can't you tell the future from the stars?" "Because!"? Or, "See your preacher!"? The Framework is the right document at the right place in the structure of education to supply the answers to these questions. It doesn't, so a goal of this work is to begin the process.

Fortunately, the Framework once again does not follow its own advice, as when it says,

> When we test forms of inquiry such as parapsychology, the study of unidentified flying objects, or astrology, we find that claims for their validity on scientific grounds fail repeatedly F90-p. 15

To this list add creationism, popular stock market analyses, and much of the current environmental movement. The Framework pussy-foots around the creation problem. Instead of taking a solid, objective stand that Creationism does not qualify as science, it leaves the word creationism unused and overstates the case for evolution. This terribly weakens the scientific position.

CHAPTER ONE
THE CALIFORNIA SCIENCE FRAMEWORK
BEYOND BIOLOGY

INTRODUCTION

California's 1990 Framework well represents those with an abiding faith in science, those who accept science as a religion. It leaves little room for the indelible uncertainty in science. In its defense of science, it errs in four major ways:

> First, while properly denying beliefs in science, the Framework mutates theories into beliefs.
>
> Second, it denies beliefs held by scientists. Scientists possess anything but unanimity in their views of the natural world. The Framework casts scientists in a most unflattering, narrow-minded mold.
>
> Third, it fails to show a consistent understanding of uncertainty in science.
>
> And fourth, it misses the opportunity to make the necessary distinction between the degrees of certainty expressed in science as principles, facts, conjectures, hypotheses, theories, and laws.

Problems like these lay beneath the Framework's handling of evolution. They continue in its treatments of Conservation in Energy and Ecology, and of Uniformitarianism in Geology.

THEORY VS. BELIEF

Science, as defined by this Strategy, is objective knowledge, and by that fact alone it holds with no beliefs. Science does not deal with the spiritual or supernatural solely because these phenomena are not measurable. If one were, of course, it would instantly lose its credentials as spiritual or supernatural. For the sake of argument, as soon as a spiritual force in nature does become measurable scientists will welcome the phenomenon into the fold.

Science excludes the spiritual and supernatural by elementary deduction from its simple definition; it does not exclude them by dictum. The latter view is consistent with the Framework when it says,

> Science is not theistic, nor is it atheistic; it does not presuppose religious explanations. Science is concerned with the mechanics, processes, patterns, and history of nature; it is neutral with respect to divinity, the supernatural, or ultimate causes. F90-p 24

In the Draft version, the paragraph above continued

> Moreover, science has no obligation to accommodate anyone's religious beliefs. Although personal beliefs should be respected at all times, the teaching of material in the science curriculum should not be suppressed or avoided on the grounds that it may be contrary to an individual's religious beliefs. DF89-p. 13

Perhaps the Great Compromise on Evolution deleted these ideas. However, quite independent of the problem of evolution vs. Creationism, the claims do not stand up to any test of reasonableness. Does respect for personal beliefs extend to Nazism? Such a disclaimer was inappropriate and unnecessary.

Science does not respect a belief in racial supremacy. On the other hand, science also cannot hold with the popular but unscientific belief in racial genetic equality. This is true for two reasons. First, there are measurable differences between the races. And second, the Scientific Method bars forming subjective standards of comparison as contained in either supremacy or equality. The deleted commentary from the Draft was another example of too vigorous a defense of science and evolution against the religious fundamentalists. The Framework simply should be above this.

Popular Issues

A profusion of popular issues with science and technology at their core bless the Nation and the World. Supporters rally around these issues with great passion, often on both sides, to build belief systems. The issue of the origins of life has become not Creationism vs. Science, but Creationism vs. Evolutionism. Rational debate is buried in the coffin of the television set. For years, the popular mode of advocacy has been the drum beat of demonstrations, punctuated with empty-headed sloganeering, and fueled by modern communications. Technical issues tried in the street are passed into law by populist legislators. Today, prestigious technical and scientific societies, along with organizations with scientific-sounding names, issue politico-economic proclamations under the name of science. Legitimate scientific societies among them have found an expedient to professional standards and a short-cut around peer group review.

Peer group review assures a measure of objectivity and upholds the standards of science. It is quite restrictive and conservative. From time to time, it even manages to protect scientists from their errors. Historically, the greatest discoveries and changes in science are brought about by the young scientists. Ironically, publication standards today favor the established scientists. The modern day technique is to skip publication and peer group review, and head directly for the press conference. Faddish subjects are those that deal with the environment or certain government policies[1]. They get quick attention and prominent coverage. The publicity dam has burst — scientists putting aside scientific discipline for the fame of publicity and the fortune of government grants.

The Media

The media throw fuel on the fire. Journalists have an appetite for the passionate and quick answers, catering to the shortest attention spans and magazine formats. Causes rank information. They find uncommercial anyone who might bother to test for economic or technical feasibility, to ask about alternative uses for the required resources, or to question whether success is achievable or measurable. The press prefers absolutes to qualified statements. Cameramen and editors deliberately frame placards and demonstrations to fill the picture, but they relegate scientists or engineers engaged in disciplined study to 30 second bites or hypnotic

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[1]The favorite target recently has been the Federal executive as opposed to actions of either the Federal legislative or judicial branches, and especially foreign policy.

public television treatises. Science is, unfortunately for its own public relations, too conservative.

No one has time to see if the popular solution exacerbates rather than solves the problem. Too many see failed domestic programs as simply examples of not enough expenditure of time, energy, money, or support. Moreover they demand these beliefs as articles of faith.

The need for an informed, skeptical press and public has never been greater. Knowledgeable people need to filter the sloppy science that fills the daily press for the sake of other citizens. The public is especially vulnerable to such shenanigans. The public is prone to hysteria and irrational belief systems. The nation has a flat EEG on the left side. Nowhere is this more true than in the environmental movement.

Environmentalism has become the new religion, the new belief system. Its dogma fills the print and electronic media. It is responsible for a wide range of legislative measures, some sensible and some not so sensible.

The nation owes a debt of gratitude to the pioneers in the environmental movement. They were directly responsible for valuable additions to the National Park System, beautiful lands in need of protection. Their work on behalf of Arctic seals and whales has raised the world's consciousness, leading to a reversal of near fatal over-harvesting of these valued species. They contributed to a major reduction in air pollution in the Los Angeles basin, a fact routinely omitted in the press. Their work continues on behalf of dolphins and rain forests. While the subjective values in these projects are beyond the realm of science, conservation is a legitimate scientific and technological undertaking.

However, over the years the movement has expanded its mission beyond conservation of life and beauty. It values the primitive over the needs and comfort of man. It cherished the lost beauty of Glen Canyon, and recognizes neither the beauty nor recreational value in the now accessible canyons bounding Lake Powell. It blocked the construction of now urgently needed dams on the Colorado River through dubious charges about damage to the Grand Canyon.

The movement has raised the cost of doing business using bureaucracy as a weapon. As a consequence, the U. S. economic network of water, highways, and energy is falling below minimum standards. Environmental impact reports with their unending challenges and appeals have placed the cost of water and power systems out of reach. Completed sections of the badly needed California water project never used fell to bulldozers. Some projects under construction lie abandoned not because of public will but because of the economic burden of the bureaucracy.

Environmentalists allege threats to variants of species[2] to block any project, giving infinite weight to the variant over the project. Every wetland, every sand dune is more valuable than any water or any electric power, and so government projects freeze in their tracks. Under the mistaken impression that conservation and recycling can solve waste and energy problems, cities and states stand politically paralyzed, unable to acquire new landfill sites or new disposal systems. Meanwhile, Californians are paying for recycled bottles and segregated trash that eventually ends up in landfills anyway[3].

The movement stands four-square against nuclear power, the safest, cleanest, and potentially most plentiful energy source. It has expanded its territory into anti-national defense under

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[2]E.g., the spotted owl, alleged to be in small numbers only in old forests, is the cause of major economic dislocations in the Western U. S. timber industry. Actually the species thrives in second and third generation growths.

[3]Recycled bottles cost about $99 per ton, while fresh bottles run about $66 per ton. The result is that no manufacturer wants to make bottles from salvaged glass. Secondly, one might be able to prove that the energy use is proportional to cost, so that recycling of bottles is increasing energy consumption, and that added energy cost is going to the dumps.

the flimsy pretext of protecting the environment. Automobiles, and the "American's love affair with his automobile", are the latest cause and matching slogan. Trains are being built in low-density areas that will be costly white elephants. Technically they cannot over-all reduce congestion, require fewer automobiles, save energy, reduce taxes, or reduce commute time except in the few highest density living and working areas. Rights of way are now being acquired for commuters to job centers that will be phased out before the first train boards. One might chalk up the train adventures to governmental make-work projects, except that the automobile represents a principal and endangered economic sector and is destined to remain the primary source of transportation for employees.

Government policy once guided by science is now guided by Environmentalism. As Creationists succeed in putting Creation Science into curricula, Environmentalists victories include seeing slow growth embraced on community agendas. To environmentalists the issue is the environment vs. growth. They lack the capacity to understand that the consequence of no growth is economic decay. The scientific issue is growth vs. entropy. Economic decline with greater environmental harm will be the long term consequences of the lack of scientific thinking in government.

Today, Environmentalism poses a greater threat to science than religion ever did. Like religion, the movement claims valuable goals that give it strength and legitimacy. However, the new environmental movement has grown to represent the anti-science, anti-technology forces of ignorance. Now masquerading as the genuine science discipline of ecology, environmentalism is a new orthodoxy supplanting science training in the education system. As the trend continues, the nation becomes more and more vulnerable to the newer breeds of charlatans who indoctrinate our children. They are the teachers who preach the Catechism of the Cataclysms.

Environmental goals such as setting aside forests, preserving "pristine" coastlines, and protecting wild animals have almost no scientific content. In this context and at this level, science is environmentally secular. In practice, improved technology will increase the yield of forest lands, reduce the hazards to coastlines, and maximize the safety of valued species. Science and technology will prove to be the effective contributors to responsible environmental and conservation activities.

Issues such as the technologies of water and power development, forecasting human and wildlife populations, atmospheric models, and epidemiological studies are fertile grounds for scientific guidance of public policy. Economics is muddied by the schools of political economists, but the economic progress of modern societies is amenable to objective, scientific treatment. Parameters that gauge physical and material well-being include the standard of living, life expectancy, leisure time, disease control, caloric intake, money, consumer purchasing power, access to information and entertainment, and both economic and physical mobility. Properly conducted cost benefit analyses using parameters like these yield highly valued and instructive engineering models.

The issue between the environment and science is not a struggle between the objective and subjective. The problem as concerns science is threefold — increasing

(a) denial and disuse of the objective,

(b) distortion and misuse of data under the pretext of objectivity, and

(c) replacement of science with belief systems.

Science education must help the public see through this anti-science wave. Scientists need to stand above belief systems and challenge each new wave of politically correct thinking with authority and vigor.

Compelling Beliefs

As the California State Board of Education says,

> Compelling beliefs is inconsistent with the goal of education; the goal is to encourage understanding[4]. F90-p. xi

The 1990 Framework underscores this idea:

> Science is not a matter of belief; rather, it is a matter of evidence that can be subjected to the tests of observation and objective reasoning. F90-p. 18

Which belief system contributed to the following quote? What evidence fits?

> Science teachers should not create a market for animals that are collected from the wild; rather they should insist that supply houses certify that dissection specimens are raised explicitly for that purpose. F90-p. 158

Scientists can respect life without such extremes. Many experiments reported in the medical literature are nothing short of inane and show a nagging lack of respect for life. Some experiments are repetitive[5], in many the purpose is not clear, and others are contrary to established theories. Perhaps biologists and physiologists just become inured to life.

Still, an independent panel[6] might approve each animal experiment, imposing a reasonable respect for life and assuring humane treatment for laboratory animals. Projects may sacrifice animals for no more than the training value, and that may be acceptable. But the activity should have a scientific point and the experimenter should have designed his work purposefully, predicting the course of his findings.

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[4]California State Board of Education, "Policy on the Teaching of Natural Science", January, 1989

[5]How many times must it be shown that training does not increase the weight of the brain?

[6]This Strategy is opposed to a Commissioner of the Animals, and recommends such a screening board only if it is voluntary on the part of industrial laboratories and schools.

Why not collect specimens from the wild? Some animals, like certain frogs and birds, are major pests undergoing systematic destruction in some parts of the country. Wouldn't it be better, that is, more ethical, to harvest them for classroom dissection rather than waste them? Why not use wild animals harvested for food for experiments as well, so long as they are not endangered? Why not use any animal so long as it remains plentiful and robust? Does the Framework's prohibition apply to insects?

The Framework's promotion of belief systems connected to animals carries over into this next quote. Here the Framework is discussing feast and famine cycles caused by a hypothetical overgrazing of a herd of deer:

> As a result the starvation rate may increase the next year, and the population may be reduced to its original carrying capacity. In turn, the abundance or condition of other organisms that depend on the deer for part of their biotic interactions as well as the entire system and its interactions are affected. (Obviously, there is a lesson here for human intervention and interaction with other living things.) F90-p. 33

To what end might human intervention apply? Why is a beaver dam more sacred than a human one? Should man interrupt the natural cycle? Does man value constancy over cycles? When forest managers prevented fires, they prompted a whole raft of unintended consequences. Certain species did not reproduce, undergrowth choked off other valued species, debris developed into a serious fire hazard, and some trees would not achieve their full growth potential. Aren't these results of cycle interruption a lesson for intervention in wild deer populations?

The following quote or a variant recurs frequently in the Framework.

> But humans have also caused or contributed to the extinction of many forms of life and continue to contribute to a rate that is much higher than at any previous time in human history. F90-p. 133

This is a belief, lacking evidence for both claims. Are these frequently repeated claims based on an estimate like the following:

$$\text{Extinction Rate} = \frac{\text{Species}}{\text{Acre}} \cdot \frac{\text{Acreage Converted}}{\text{Unit Time}} \;?$$

Any such estimate in science demands corroborating data for the factors and relationship on the right hand side!

Here is yet another belief from the Framework:

> The very strong magnetic fields produced by superconducting magnets ... pose unknown risks to the human body. F90-p. 72

Like the previous loss of unknown species, this statement claims the existence of something unknown. Does "pose unknown risks" make any sense at all? What evidence supports the belief in a danger? Has anyone reported scientific evidence of such an effect? Are studies underway? Someone must have studied the effects of magnetic fields on animal tissue or man, and the Framework should cast the results in responsible scientific tones. More subtly, are magnetic fields from superconducting magnets worse than other magnetic fields[7]?

Even the following quote is objectionable:

> "Sometimes [heat] is an environmental pollutant, as when river water used for cooling is warmed so much as to affect the ecological balance of the river." F90-p. 62.

The word *pollutant* contains a value judgment. This is unscientific, reflecting personal beliefs of the author. The issue demands a scientific model that supports the thesis that a particular change in the so-called ecological balance is bad. The Framework's statements on beliefs serve as counterpoint

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[7]For example, Nuclear Magnetic Resonance (NMR) medical imaging? Note also that NMR was changed to Magnetic Resonant Imaging (MRI) because of public fear of anything with nuclear in the name!

to its own extravagant sections promoting beliefs. These passages support the essence of a major criticism of the Framework itself. One of the more flagrant examples of excess is its treatment of conservation.

CONSERVATION

In spite of its politicizing, Conservation remains a rich scientific and technological issue. Having many forms, it is near the top of the list of current political causes, with well-meaning people, politicians, and others choosing sides. Sometimes conservation refers to preserving natural scenic wonders, but more often it translates into reduced consumption. Still, the field yields to mathematical, thermodynamic, and economic modeling.

Sadly, the Framework speaks on Conservation not with the voice of the scientist but with the voice of the ideologue — opinionated, unsupported, and marked with appalling inconsistency. The author of the following passage has managed to boil down today's Conservation Activism to its illogical, unscientific essence:

> Conservation should not be taught simply as a matter of classic Malthusian population growth according to which natural resources are stripped by unchecked population control. Rather, there is now a neo-Malthusian component: Some populations use more of the available resources than others. For instance, Americans may use 50 times more energy than the average resident of India; as 6% of the world's population, the United States uses 40% of the world's resources. One additional American, therefore, can have a disproportionate effect on the world's supply of resources. Students should be educated about these perspectives in order to help them make informed judgments about their habits and priorities and to help them to set policies for the next generation. F90-p. 21

This paragraph requires dissection and the application of a dose of scientific criticism in five areas.

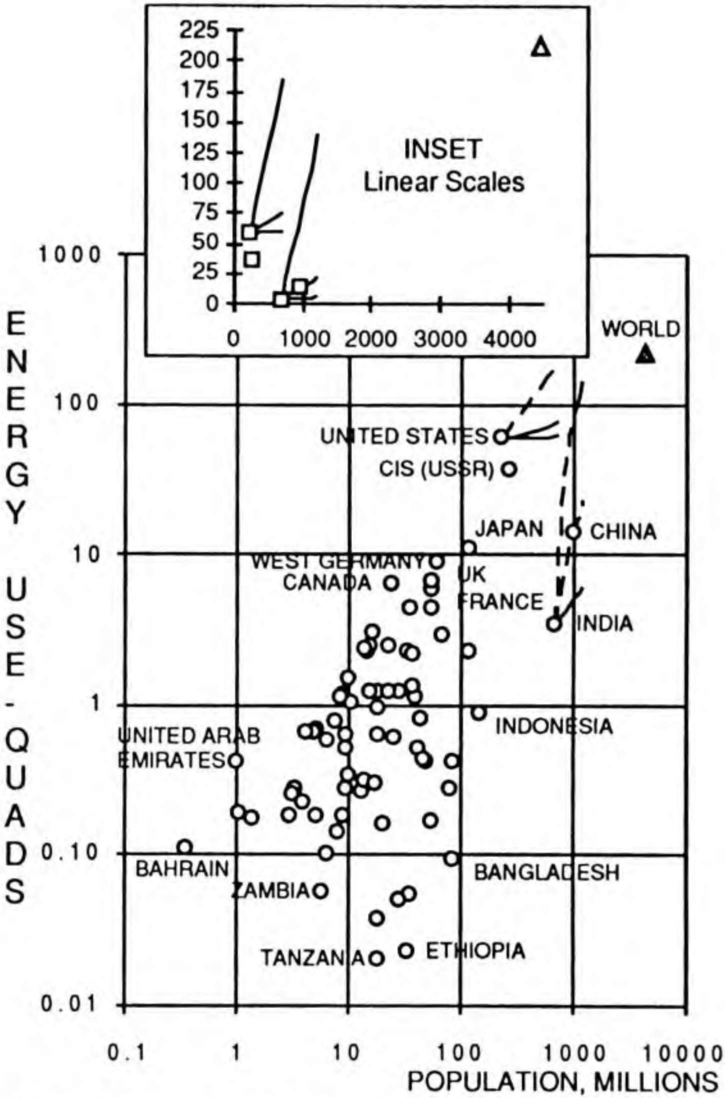
1. The framer implies that educators *should* teach conservation "as a matter of classic Malthusian population growth", just not exclusively so. The Framework uses Malthusian as a pejorative, much as Machiavellian might be. Malthus was a highly regarded and internationally honored statistician and demographer. He would undoubtedly be most chagrined to see the state of knowledge of this framer of science education!

2. One can sense the author's pain at the injustice when he claims that Americans use a disproportionate share of resources. There is no scientific theory that proclaims that uniform distribution of resources or wealth is best or just in any sense. Even if it were true, it would not be science. On the contrary, one can postulate legitimate, empirical economic theories that say that clusters of wealth (capital formations) are the engine of economic systems. That capitalism maximizes the well-being of whole populations. Three times in this brief paragraph the author distorts statistics to promote egalitarian beliefs under the guise of science.

3. Why has the author chosen *conservation*, the decrease in consumption among the affluent, as the solution to non-uniform distributions? A more humane, practical, and beneficial solution is to target the needy populations with *increased* consumption. In fact, that is exactly what needy implies.

Suggesting that conservation is a flawed concept is not at all popular in the United States today. Turn the idea around to make a point about development for the needy. Then it gains immediate popular support for technological advancement.

4. How might one substantiate the claim that an additional American has "a disproportionate effect on the world's supply of resources"? To support such a claim scientifically, one needs to know the marginal use of energy, to adapt a phrase from economics. The next figure illustrates the problem.



ONE MORE AMERICAN REQUIRES MORE ENERGY THAN ONE MORE INDIAN?

Figure 1-3

This figure shows the energy consumption of 74 leading nations of the world plotted against their populations. The triad of dashed lines at each location represents three different paths for increased energy usage with increased population. The upper line is an incremental rate equal to the U. S. per capita consumption, and the lower line is equal to the Indian per capita rate. The middle line is the geometric mean of the two. Because of the extreme logarithmic distortion necessary to display the data, an inset shows the same figure on a linear scale.

Would the U. S. follow its upper path and India the lower? That is what the Framework claims! The data shown here cannot support any kind of conclusion of this type. In no way does plotting energy use against population create a model for dependency of one parameter on the other. The very form of the data is inconsistent with any conclusion such as: "The marginal increase in energy use will be greater or less than the current average." Or, "the increase in energy use in India would be less or greater than the increase in the United States." The notion that an extra American has a disproportionate effect is poor scientific speculation. It rests on some non-existent theory about the rate of energy usage per capita. It is an extrapolation from a "follow-the-dots" model.

One might reasonably postulate that the growth in energy use in India will *exceed* that of the U. S. First, it needs to! India has a much greater need for additional energy than does the U. S., and the U. S. is in a mood for conservation and living with shortages. An extra American might have an imperceptible effect on U. S. energy usage, while one more Indian, because of inefficient use of all resources on the subcontinent, places an excessive and undeliverable demand on energy there. Most importantly, the unprecedented wealth in the U. S. lies in its industry. Our energy use per capita should be least sensitive to population when compared to other nations.

Of course, the problem in each country is much more complex than this simple analysis. First, the hypothesis of a direct

Cause & Effect between population and energy use is an improbable beginning. India has no elasticity in its energy consumption. The extra child there will most likely result in an extra premature death with no commensurate change in energy use. In the U. S., the issue rests on real economic factors, not on hypothetical values placed on non-renewable resources. The U. S. has the wealth and investment in delivery systems to tax energy usage in various ways according to political, not technical imperatives.

5. The article tacitly assumes some theory that there exists a limit on energy usage and implies that the Earth might be close to it. Scientists certainly can speculate about such a thing, and should. They might put some astronomical bound on energy consumption, but it simply hasn't developed as a theory of science.

Earth scientists estimate a parameter called the solar constant, a number that represents the total energy impinging on the earth from the sun. That number is equivalent to 5.2M Quads[8]/year, greater than four orders of magnitude as great as man's generation of energy! A one percent fluctuation in solar emission is more than two orders of magnitude greater than man's energy use. A one percent variation is about the peak to peak change in the 11 year solar cycle, and about half the estimated variation over several centuries. In view of the tolerance of the earth's biosphere to naturally occurring changes, man's energy consumption simply is not likely to have any upsetting influence for some time.

In summary, educators should tag this one poor paragraph on Conservation for a framework on comparative social studies. It confuses problems of growth with the potential for Conservation. What does such teaching do to legitimate claims for Conservation? How great is the harm in indoctrinating our children with erroneous messages? How

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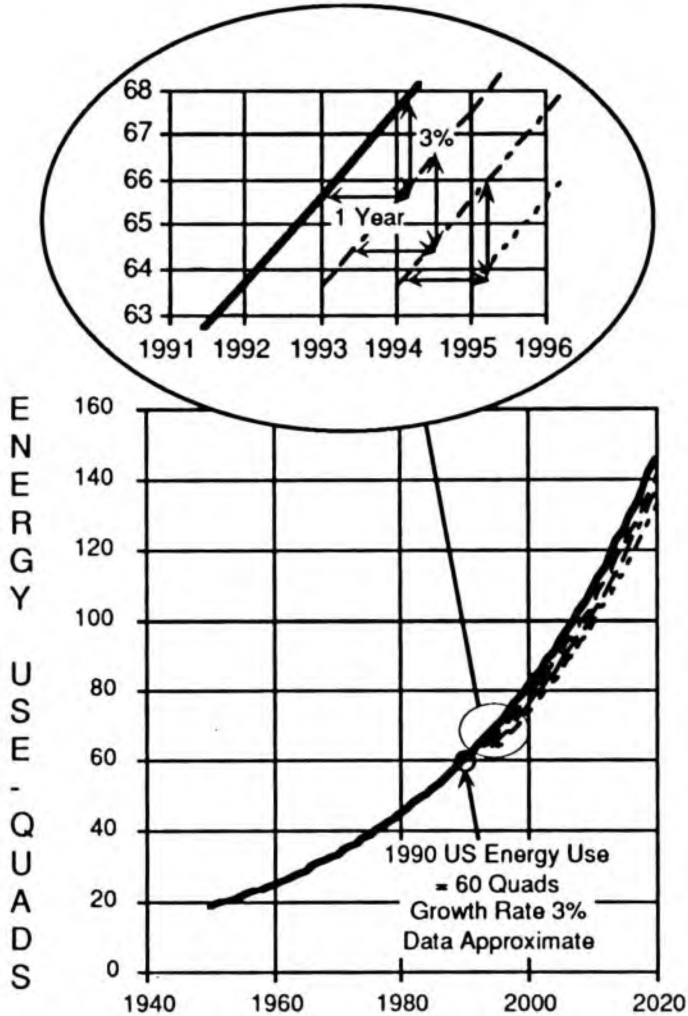
[8]A Quad is a quadrillion or 10^{15} BTUs (British Thermal Units).

much harm is done to them by teaching them to accept such non-critical thought processes in the name of science?

Technically, conservation is no more than a temporary solution to shortages in a growth commodity. This observation applies to any commodity which is proportional to either a growing population or to a growing economy. Almost any geometric growth rate soon overtakes any improved efficiency in usage. The author should have learned this somewhere in K-12 mathematics. A one time reduction in consumption just buys a little time. The effect is shown graphically on the next page.

Long before a student ever receives formal instruction in analytic geometry and the Cartesian coordinate system theory, he would be receptive to a graphical construction of energy consumption in the U. S. vs. India. The teacher could energy consumption in the U. S. vs. India. The teacher could demonstrate the graphical effects of the wished for improvement in efficiency of usage. He could graph the total consumption for each nation. He could discuss the effects of population growth rate coupled with an increase in efficiency. He could show how efficiency buys a little time.

The three percent growth rate used in the chart is a typical figure for the long run growth rate of free market economies. It fits historic trends in the U. S. Gross National Product (GNP), and is a reasonable forecast for continued GNP growth. Because of the strong correlation between energy use and GNP, 3% growth is also a likely estimate for continued energy expansion, unless the environmental movement prevails with its zero growth agenda. Unfortunately, no economy succeeds at zero growth; the choice is grow or decay.
Population growth poses serious problems on a world-wide scale. It is even acute locally, as in California, where statewide water rationing is in effect. Additional water supplies and storage are still a decade off, thanks to misguided, unscientific conservationist thinking as promoted in the California Science Framework. Groups in California have tried to stop growth by restricting water services. They



CONSERVATION
CUT BACK ONE YEAR'S GROWTH,
GAIN ONE YEAR OF TIME

Figure 1-4

claim that water conservation will solve the State's problems, and all that the State needs to save the environment from the ravages of water development is ZPG (Zero Population Growth). What they are likely to accomplish is the conversion of economic growth into economic decay, creating a much more serious problem than any feared population growth.

Responsible Conservation requires reckoning the cost of the conservation into cost benefit formulas. For example, the scientist should compare the cost of insulating a home, whether computed in dollars or BTUs, with the corresponding savings in heating energy. In the United States, the action of the market tends to work this equation to the ultimate benefit of the consumer. The advanced student can also learn that the effects of the prevailing interest rate is to weigh up-front costs more heavily than future costs. This present value computation is well within the capacity of high school mathematics.

The best answer to energy usage is not simply a financial balancing of the net expenditures, even corrected for the present value of money. In today's international environment, an extra margin is advisable to account for reducing the risk in political arrangements and situations. The nation's strategic petroleum reserve is an example.

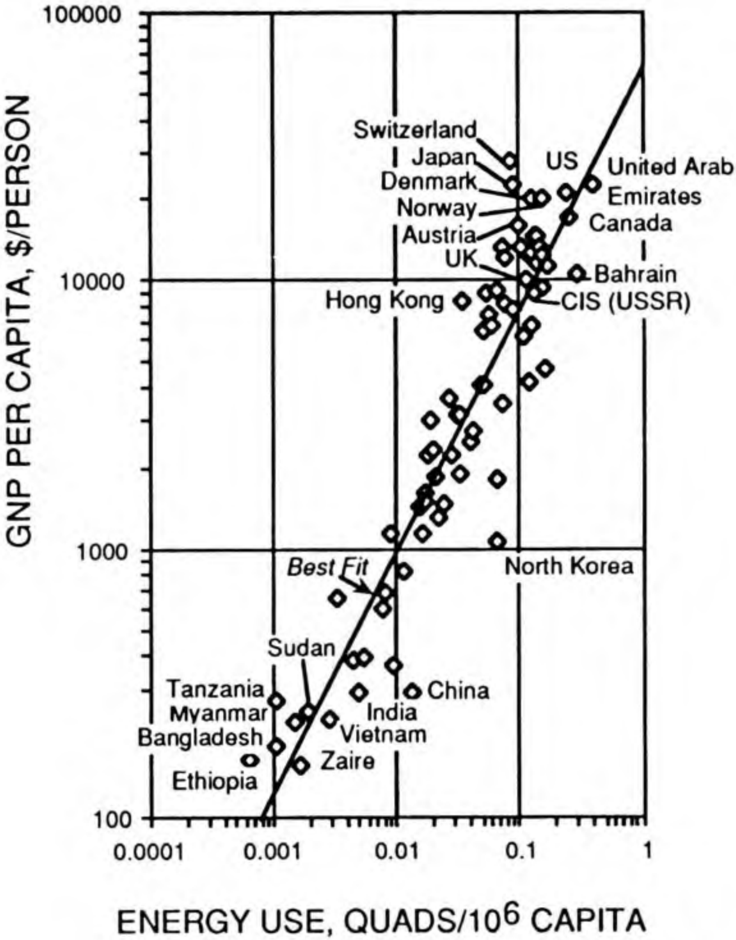
ENERGY

The Framework's pitiful section on Conservation ignores the strong correlation between energy usage and material well-being, or standard of living. One needs little familiarity with graphs to see the strong effects depicted in the figure on the next page.

The Framework itself hints at recognition of this empirical model:

> The standard of living we currently enjoy is a direct product of science and technology. F90-p. 160

Science does not give full credit to statistical correlation as the sole foundation for a model, however. The reasons for this



ECONOMIC STRENGTH DEPENDS ON ENERGY USE

Figure 1-5

get ahead of the story, but a little thought will show the beneficial effects on humanity of energy usage. For example, examine the food production cycle. It consumes energy at every stage, as outlined here:

- research & development
  - on animals
  - on equipment
- land preparation
  - roads
  - clearing
  - tilling
- seeding
- fertilizing
- irrigating
- environmental control
  - of weeds
  - of pests
  - of weather
- harvesting
- preservation
- packaging
- shipping
  - at each stage
  - including consumer's trip to the store
- storage
- preparation
- waste management

This relation can be found in any activity or industry of man. It is the theoretical foundation for the theory about the dependence of economic strength on energy consumption. The data constitute confirming empirical evidence.

> The class should discuss the network provided by both government and support industries that makes the feeding of a nation or a world possible.

The pedagogical exercises above will enable students and teachers alike to understand the critical differences between mined or otherwise harvested fuels and manufactured alternative energy sources, like alcohol or electricity, including the battery. Perhaps students and teachers so trained will understand the problem with statements like the following from the Draft Framework:

> If the energy is taken from a renewable source, such as the wind, the sun, water power, or nuclear energy, ...
> DF89-p. 82

Nuclear energy might be virtually inexhaustible, cleanest, and safest, but it is not renewable.

A whole energy-consuming network, commonly known by the overworked word *infrastructure*, supports the feeding of America and the world. Here's a positive, counter-ideological exercise for K-12 students. Teachers could scale it to any level of sophistication.

A teacher, a class, or an entire school sincerely interested in energy studies, might try completing the study table on the following two pages. Each box could be a separate project for student research.

For lower grades, the entries might be subjective evaluations for discussion. In higher grades, students should quantify the entries[9].

Trace out the delivery and consumption of food, backward from the consumer to the farm family and all the things that support them. Trace back to the organizations and companies that he needs, including universities, seed manufacturers, chemical companies, machinery manufacturers, utilities, storage, preservation & packaging, harvesting. Include processors, packagers, and shippers. Include highways, railroads, air freight. Add in support services and consumables, like utilities, fuels, advertising, warranties, legal fees,

[9]A good starting point for these data is a report by the National Research Council entitled, "Energy in Transition 1985-2010."

ENERGY PROJECT		Exhausability	Renewability	Safety
Source		Years until gone	BTU per Year	Risk, diseases deaths per year
Fossil	Coal			
	Natural Gas			
	Petroleum			
	Geothemal			
	Hydrogen			
Nuclear	Fission			
	Fussion			
Solar	Alcohol			
	Hydroelectric			
	Radiation			
	Wind			
	Wood			

Table 1-1L

Environment	Efficiency	Technology	Cost	Portability	Power
Air, water, heat, ground esthetics	Production, conversion delivery, Quads/quad	Development, Maturity	Investment, $/BTU	BTU/pound, recovery machinery	Quads (10^{15} BTUs)

Table 1-1R

charitable activities, taxes. Estimate the levels of energy and labor required.

Make a birth to death flow chart for a familiar object, such as a food container. Where do the materials come from, what work (energy) is required to make the container? How is it shipped, labeled, filled, stored, and sold? Trace out its disposition, i.e., recycle vs. reuse vs. trash. Trace out cost, energy, labor, pollution, taxes, profit.

For pollution, include biodegradability, land fill, air pollution, heat, electricity sources. Compare plastic, fiber, glass, aluminum, steel. Discuss convenience, safety, investment strategy, marketing, public policy as in taxation and regulation.

What happens if some of the links in the chain are missing, as the Eastern Bloc nations recently discovered?

Students should subject shelter, health care, and emergency services to the same treatment. The Framework's authority on Conservation should lead students in a study on the impact energy usage had on humanity by comparing the differences in all effects between a 6.9 earthquake in San Francisco and a similar one in Armenia! These are hardly Malthusian values.

Unchecked population growth and energy use are negatively correlated. This technical term means that movement in one tends to predict the opposite movement of the other. Unchecked population growth occurs in India, not America! East Indians need to consume more energy, not Americans less!

Except for immigration, the U. S. has achieved zero population growth. Worldwide, people are migrating as deep into the Western culture as possible. They do so assuming exceptional personal risk, in part because of the human values delivered by our use of energy. The Framework overlooks the power per person relationship to standard of living.

Recently, the National Academy of Science (NAS) issued a widely publicized paper calling in part for a national policy of higher energy prices. Ostensibly, this will increase energy efficiency and promote conservation. The following theorem might not be too difficult to prove:

> Hypothesis: Cost of a competed[10] product or service is directly proportional to the total energy expended from first effort to end delivery.

This does not say that energy content is the only parameter affecting cost, but in a first order model it is the primary factor. If adding insulation costs more than the fuel costs it saves, then adding insulation likely require more energy! If the government taxes end use energy, of course the public pays it. This increase in taxes reduces the incentive to produce. It creates shortages in the long run. Also, the same type of tax will cause the cost of insulation to rise proportionally. A tax on energy end use will not cause efficiency through economic pressure.

The economic argument must include the time value of money. The NAS might argue that one time insulation costs save energy over a lifetime of the equipment. Note, though, that this lifetime is still finite so that one cannot give infinite weight to the eventual savings. Second, as discussed above, the time value of money works solidly against up-front costs. Deferred expenditures cost less.

The popular concept of energy use is home air conditioners and the automobile. Manufacturing, transportation, and agriculture consume most of the nation's energy, not personal air conditioners. The automobile plays a dual role. The crush of rush hour traffic is unmistakable evidence of the automobile's economic importance to industry.

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[10]A competed product excludes works of art and scarce products.

A larger principle is at work in the closely related strands of conservation and energy. Even if the framers can justify their views about these fields, the methodology outlined in the Framework amounts to indoctrination in a belief system. In no way can the goal of science education be better citizenship through conservation. The goal must be critical thinking. Educators should teach children to challenge every tacit assumption and tenet in the popular causes built around conservation and energy generation. Teachers should prompt the class to doubt each claim. Children should come out of the classroom confused as to where the teacher stands on conservation and energy[11] use, but absolutely clear about how one can dissect theories.

SCIENCE AND SOCIETY

A traditional objective of science is to provide government with the means, through technology, to furnish all the services demanded by the people. A corollary objective is to provide the people and their representatives with valid, objective data, not a political agenda. The Framework has a different approach.

> The theme of Energy is important to considerations of ethical behavior and the relationships of science and technology to society. F90-p. 29

This statement happens to be true, but not at all in the sense of the author's larger message. That Framework's clarifies its message in passages like these:

> Humans have surpassed the carrying capacity of the planet, as evidenced by changes that society cannot

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[11]Or the Big Bang, Evolution, Recycling, Greenhouse Effect, Deforestation, the Atom, Subatomic Particles, AIDS, National Defense. Teachers should be allowed to show their unequivocal emotional and ethical disgust on issues such as promiscuity, Murder and Suicide, Drug Use, and other criminal activities, for they are role models and authority figures who can reinforce socially valuable behavior. But the teacher who also shows by analysis and reasoning why these things are wrong will have the more lasting effect.

> reverse, and that are causing the deterioration of atmospheric, oceanic, and ecological systems. DF89-p. 112
>
> Science alone cannot resolve the problems inherent in modern society (e.g., conservation, waste management, pollution control). DF89-p. 123[12]

and

> Technology may not find answers fast enough to counter the impact of expanding human populations; therefore, people will have to make difficult but well-informed decisions about planning families and planning their use of environmental resources to the best advantage. F90-p. 24

Each of these statements contains some elements of truth. Science, presumably including technology, may not be *allowed* to solve problems created as by-products of older technologies. The public, the government, or other practical considerations might bar technological solutions. The implication in the Framework, however, is that the student should look to non-scientific means to solve these problems. Within the field of science, that is indoctrination, not teaching.

Ideologies have no place in a science framework. They are invitations to radical social activism, and run against the principles of science. They are contrary to objective understanding, and prevent science from pursuing its mission of serving the interests of society.

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[12]These last two quotes were tempered in the 1990 Framework. They now read, with emphasis added,

> In some areas, humans have surpassed the carrying capacity *of their regions, which has caused widespread famine and further* deterioration of atmospheric, oceanic, and ecological systems. F90-P. 141
>
> Science alone cannot resolve the problems inherent in modern society (e.g., conservation, waste management, pollution control), *but it is an essential component of any such resolutions*. F90-P. 154

Passion may be the route to political power, but it is a poor substitute for reason. In fact, between passion and science, the former is today the more effective means of influencing our lives. Political activism may make for viable livelihoods, and perhaps then it is worthy as vocational training in our schools. If so, teach it in social studies, not science!

The Framework supports the beliefs that the ecological problems of 20th Century America are, first, inherent, and then that they are peculiar to the modern setting. The Framers have no evidence to support these beliefs. Pollution in the backward countries is appalling by Western standards. By one report, the city water in Moscow contains human intestinal parasites. One needn't go to Armenia or India to see the effects of science and technology on our standard of living.

> Students in elementary school should take a walk through one of the Mexican border towns, or see tapes on Russia or East German manufacturing towns. Back in the classroom, they should discuss what they observed.
>
> What was the condition of the air? Did they see a difference in the condition of roads and general cleanliness? Did they see evidence of the lack of plumbing, of sewage systems, and of water systems?
>
> What can they say about the medical system and diet by observing people on the street?
>
> They should read about the Black Plague that ravaged Europe and discuss it from similar scientific aspects.

A legitimate goal of science and technology is to seek ever cheaper forms of energy for mankind, delivered at ever smaller costs, and consumed with ever less pollution. San Francisco should serve as a prototype for Armenia, not the reverse.

Again in the environmental regime, the Framework presents a belief as fact:

> Chemists continually create new atomic arrangements to fill human needs. For example, compounds are being synthesized to replace the commercially important Freons[13] that do damage to the ozone layer of the upper atmosphere. F90-p. 47

The statement should be recast as a hypothesis. Legitimate concern exists over the possibility of destruction of the ozone layer, and field measurements are continuing to determine if the hypothesis has any predictive value. Beyond that, scientists still need to affirm that ozone variations due to other causes do not dominate, and that the forces of stability that create and sustain the Earth's atmosphere including the ozone layer will not overcome present manmade effects. One can hypothesize that through feedback the destruction of ozone would cause natural processes to increase the production of ozone at a compensating rate. Today's scientific models are not sophisticated enough to either support or refute this conjecture of stability in the earth's atmosphere.

Models for the atmosphere are primitive. Until scientists can make them more accurate, erring on the side of caution may be politically responsible. Meanwhile, scientists have an ethical responsibility to explain what they know and what they don't know. In no case should they permit the indoctrination of our children with scientific speculations disguised as facts, no matter how significant and attractive the notions are politically. The issue of ethics in science begins here.

On the other side of the ledger is the following quote from the California Science Framework:

> Major issues such as the impact of human population growth on other species and on world resources and environmental deterioration, are to be discussed in an open manner by all students, not just those headed for science careers.

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[13]CFCs (chlorofluorocarbons) is preferable to "Freons" here. Freon is a registered trademark, representing a certain set of CFCs produced by one manufacturer.

This positive statement adds weight to the charge of unevenness in the Framework. The Framework should effect this view as policy, not as a waiver or disclaimer for its own excesses. Unfortunately, the Framework continues in the wrong direction:

> The science curriculum in all science courses, without exception, provides opportunities for such interactions; students participate in model debates and forums on public issues, such as water use, air pollution, gene splicing and biological species conservation. These exercises employ proper, data gathering from both science experiments and surveys. ... F90-p. 165

Debates on public issues represent the highest of academic standards. Tragically it is notable by its absence from our Universities. Educators should apply the principle of debate liberally in our schools. Public issues are rich in non-scientific, subjective aspects — economic policy, growth policy, the role of government, standards, political power, individual rights, the role of the family, and even religion. They are much less objective problems for science instruction, and there is a danger that some might interpret the quotation cited above as a permit for more non-scientific indoctrination. The whole of these problems needs airing in public debate with participation by all concerned disciplines. The science curriculum should raise other, non-scientific issues. This helps students prepare for debate in the larger arena, and helps them sort out which is science and which is not. The debates themselves are not science, and should not be i the science curriculum.

UNIFORMITARIANISM

Uniformitarianism appears in the Encyclopedia Britannica as a school of philosophy and a theory in geology. Under geology, it says of this 1832 theory,

> This principle is fundamental to geologic thinking and underlies the whole development of the science of geology. The expression Uniformitarianism, however, has

> passed into history, for the controversy between catastrophists and Uniformitarianism has largely died.[14]

The Framework need not resurrect or perpetuate this bit of antiquity, its importance in contemporary geology notwithstanding. It is well worth mentioning in passing as a scientific principle in geology, but it remains a belief or a hypothesis, subject to scientific challenge if in no other way than its etymology. It is not, as the Framework says,

> The law of Uniformitarianism F90-p. 205

In one place, the Framework corrects for this error, calling it first "the principle of Uniformitarianism" just before saying

> It is a primary working assumption of science as we approach questions of time and the past; it is an affirmation of method and of empirical reality that is necessary in order to draw any scientific conclusions at all. F90-p. 90

The first part about a working assumption is in full accordance with scientific practices. When it is tacit, however, it is not an affirmation of method. If it were an affirmation of empirical reality, it would have the confirming evidence necessary to be advanced as a model for validation. The last part about otherwise not being able to draw "any scientific conclusions at all" is a sad concession.

Scientists are looking for counter examples to Uniformitarianism. For example, physicists today ask whether the gravitational constant G is indeed constant in either time or space. The Framework says,

> ... the laws of the nature are the same everywhere in the universe. F90-p. 86

Part of the Big Bang theory holds that the physics of the first few instants of time were quite different from those in the Universe today. Uniformitarianism suggests that there was a

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14EB86, Vol. 12., p. 131

step transition from a World in change to a globe in *steady state*[15].

Indeed, is it logical that the World is today in steady state? Physicists today are searching the skies for the first confirmation of a black hole, and indeed may have found it. The black hole is a mathematical model derived as a consequence of Einstein's theory of relativity. The model has a singularity at the core, a point where gravity and density become infinite and time ceases to exist. Hawking likes to suggest that this singularity might be a door to another universe where matter sucked into the black hole is deposited. If scientists were to validate the black hole model , it would seem also to provide the first confirmation of the infinite. Where in this astronomy does Uniformitarianism apply?

Uniformitarianism presents big philosophical problems for science. Science attempts to predict, and in geology as in

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[15]Steady state is related to more primitive and difficult to define concepts of *system* and *state*. Each of these latter two notions is sensitive to the context, and must be defined or somehow well understood from the usage. One person's system is another person's subsystem or vice versa. A *system* is any collection of parts or components which comprise a greater whole for some purpose or function. A system can be *open* or *closed*, meaning that it interacts with its environment or does not, respectively. A *state* is a descriptive condition for a system which is meaningful for the application and usage. So what constitutes a state is quite sensitive to the scale of the observation, as for example, whether the view is microscopic or macroscopic to any degree whatsoever. In science, the state must also be measurable, that is, comparable to a standard and determinable within a specifiable accuracy. A state can be a dynamic or a static condition, and the permissible states in general can include both as when an organism may be alive or dead. *Steady state* then means that the state is not changing, and change can apply to time, position, or any other parameter the observer might wish to use. A system can be in steady state in either a closed or open sense, but if it is in steady state in an open sense it may be forced to remain in its steady state by an outside influence.

archaeology and astronomy this takes the form of predicting future observations of the past. Prediction necessarily involves projecting from facts and validated models those things that form patterns. These patterns extracted from nature might never change in our experience, like the local attraction of gravity. Other things, of which there are abundant examples, change but with a constant pattern of change, like the seasons or solar activity.

Saying that science requires no assumption of constancy is a major understatement. Scientists use data to reveal constancy. To presume à priori that certain parameters have not changed in time or space is to skate on thin ice in science. The problems with the treatments of evolution in biology and Uniformitarianism in geology are parallels.

The scientific way to handle such assumptions is as hypotheses or principles, and then see what conclusions result. Scientists should always declare, especially for public consumption, that the theory is operating under certain, specific assumptions. This approach strengthens, not weakens, the science.

CONSENSUS AMONG SCIENTISTS

Scientists are humans, subjective beings who happen to practice the objective branch of human knowledge. This is a key message for students in the K-12 experience. Scientists take subjective satisfaction in the knowledge gained from their work. They hold subjective beliefs about why science has answered their questions, about where science is going, and even by what route scientific research is most likely to succeed. They are fallible humans, able to make fantastic leaps of imagination when not challenged. Scientists practice objectivity professionally, but they are far from exclusively objective as a result of their work. If they were infallible, they would not bother with peer review.

Good scientists, wearing their professional hats, will identify their positions and qualify their statements appropriately. Speaking in this way for their science, they will not be stating beliefs. When a scientist begins, "I believe that ... ", he is stepping out of that objective character and speaking for his personal beliefs.

The Framework says,

> Content should also be presented as what is understood in science, not qualified with modifiers ("many scientists believe") when dealing with robust scientific conclusions. F90-p. 201

This is an excellent statement because of the word *robust* in the qualifying clause. *Conclusions* taken out of context is too strong, however. Little in science is really as conclusive as the Framework would have the student and teacher believe. Moreover, challenging established laws and theories is a high standard of scientific practice.

Frequently, the Framework is unnecessarily defensive about science, as in

> Nor should students be told that "scientists believe." ... A phrase such as "many scientists believe ..." misrepresents scientific inquiry. It also obscures for students what scientists really do, and how they come to their understandings. F90-p. 18

Scientists are subjective animals, and in spite of the virtues of objectivity in a human, the Scientific Method demands objectivity of them only in the practice of their art. Rather than being a personal trait, objectivity is a direct product of the Method.

> "One good control of scientific objectivity is the repeatability of science. That is, any observation ought to be repeatable, and capable of being confirmed or rejected, by other scientists." F90-p. 14

Neither the observation nor Science is the repeatable thing. Observations are too general, and include subjective perceptions. The first step in objectivity is to compare the observations to standards. In the most general sense, this is the process of making measurements, or creating facts. Science looks for repeatable things, called *patterns*, in the measurements. The descriptions of the patterns are *models*. To the extent that any model works, it presumes Cause & Effect to predict that the pattern will persist under some minimal set of criteria. The thing rejected is not observations but the model.

The scientific community automatically subjects any novel facts to tests for repeatability. Science measures repeatability statistically in terms of variability or accuracy. The process of reducing an observation to a measurement is not complete until an assessment of its accuracy is available.

The Framework is way off the mark when it claims that science rests on subjective perceptions:

> "When we say that all science is based on observations, the meaning is quite clear. We use the evidence of our senses (seeing, feeling, hearing, etc.) to obtain the information on which scientific work is based." F90-p. 16.

Science builds on measurements, notwithstanding the fact that eventually the measurements are sensed and perceived by a human. We use our eyes to read a ruler. Science is based on a comparison with the ruler, subject to our errors in reading it.

THEMES

The California Science Framework introduces themes, the "big ideas of science, larger than facts and concepts", in its 1990 edition. It proposes six "big ideas",

Energy,
Evolution,
Patterns of Change,
Scale and Structure,
Stability, and
Systems and Interactions.

It then attempts to weave a program of curricula, implementation, materials, and assessment about them.

The notion of themes is intuitively most attractive. However, the Framework does not earn a passing grade for the effort. It strains the concept when it tries to annotate instructional material with references to the themes. It misses many of the major points of the themes themselves, especially in Energy, Stability, and Systems and Interactions.

The Framework damages the concept of evolution through vagueness and by elevating it to scientifically unjustified levels. It promotes the belief system of environmentalism. It vainly tries to achieve a badly needed integration of science through the thematic structure, ignoring or avoiding opportunities to improve science teaching through genuine curricula and instructional integration. It furthers the compartmentalizing of education by promoting earth sciences as an equal partner in a troika with physical science and life science. It furthers the disintegration of science education by weakening the role of language arts and mathematics.

A highly damaging aspect is the Frameworks ducking of its own authority and responsibility. It diffuses its responsibilities through waivers and disclaimers as to its own selected set of themes.

> What are the major themes of science? Science can be organized in many ways; those presented here should be regarded as only one way to integrate the overarching concepts of science into a curriculum that spans scientific disciplines. The suggested arrangement of themes is designed to encompass and connect a great deal of the basic data and evidence of science. No doubt there are alternative arrangements that would work equally well. The important point is that at least some thematic structure will improve the recitation of disunited scientific facts and examples that has come to pass for science in many current curricula and instructional materials. F90-p. 26-7

and

> The emphasis on themes in science curricula provides a focus around which the terms and concepts given in an

> instructional program may be evaluated. One danger, however, is to take too literally the limited number of themes that are suggested in this framework. Other formulations are possible: Diversity, matter, hierarchy, motion, and conservation are examples of other themes around which curricula might be organized, and there are certainly many more. Other sets of themes are also possible; Project 2061, for example, uses systems, models, constancy, patterns of change, evolution, and scale. The point is for educators to ask of curricula and instructional programs, Why is this material being included here? What larger purpose does it serve in explaining this discipline or concept of science? Theses provide some guidelines for this kind of evaluation. F90-p. 36

What are teachers and the authors of curricula and textbooks supposed to do for themes?

The Framework's selected themes suffer from poor structuring and overlap. They do not represent a scientific taxonomy of science and need to be redone along some logical, scientific line of reasoning. This strategy proposes to solve this problem by selecting the elements of the Scientific Method as themes.

The Framework seizes upon the idea of themes from Project 2061: Science for All Americans. Project 2061 is a program of the American Association for the Advancement of Science for the reform of science education. The first phase, Science for All Americans, is a report issued in twelve chapters by their National Council on Science and Technology Education. The authors of the Framework find authority in the National Council's work to adopt themes to the exclusion of their other recommendations.

Themes are but a small part of the complete set of recommendations in the Project 2061 report. The complete set of recommendations are in the chart on the next page, constructed from the Project's own summary report. Themes appear at the third Phylum of the third Kingdom, and at that location only four Classes survived in the Association's Summary document. These are

Systems,
Models,
Stability & Change, and
Scale.

The main Project Report contains six themes. In preparing their Summary, the Association merged Constancy and Patterns of Change into Stability & Change, and dropped Evolution. The Association's thematic structure underwent a little evolution of its own during Project 2061:

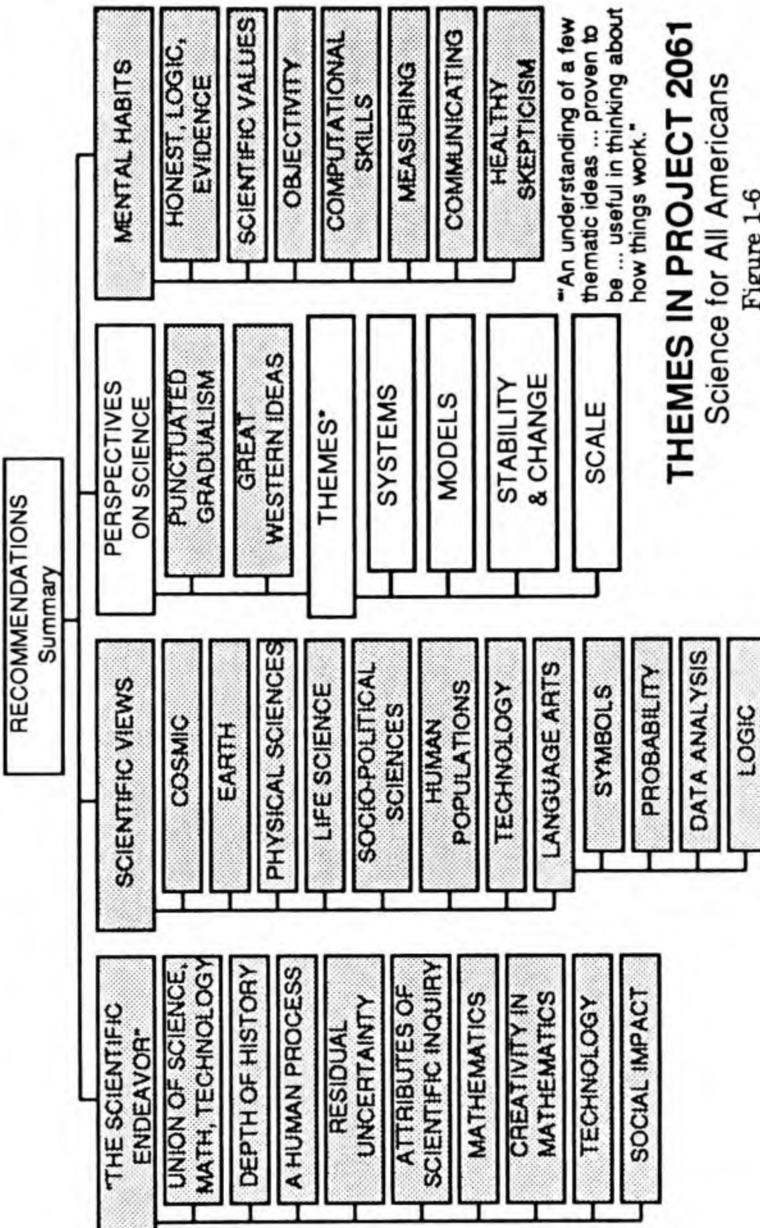
Main Report	Summary Report
Systems	Systems
Models	Models
Scale	Scale
Patterns of Change	Stability & Change
Constancy	[merged above]
Evolution	[dropped]

PROJECT 2061 THEMES
Table 1-2

To be as fair as possible to the Framework, the Project Summary may intend to give somewhat more prominence to themes than the chart on the left would suggest. The first recommendation the Summary cites in the introduction is the softening of boundaries between traditional disciplines, plus the rather thematic idea of emphasizing the connections between them. It uses the transformation of energy, which is prevalent among almost all systems, as an example.

Still, Project 2061 ranks the history of science on a par with themes in one of its last introductory paragraphs, saying

> The council also calls for some knowledge of the most important episodes in the history of science and technology, and of the major conceptual themes that run through almost all scientific thinking.



THEMES IN PROJECT 2061
Science for All Americans
Figure 1-6

While the Project 2061 Summary deleted evolution as a theme, it does speak thematically of "evolutionary change" in stars, organisms, and societies. This rather ambiguous language is simply not precise enough. It provides little help for science education, and it is inappropriate for management of the public controversy stirred by evolutionary theory. As the Framework itself says,

> The process of teaching science requires a precise, unambiguous use of language and a clear demarcation of the criteria, power, and limits of scientific investigation. F90-p. 14

These ideas are more important in science than they are in its teaching! That precision leads directly to the linguistic abstractions of logic and mathematics. It makes objectivity and hence science itself possible.

Certainly the authors of the Framework were under no obligation to follow the dictates of the American Association for the Advancement of Science. Still, once the Framers used Project 2061 as justification for their new approach to science education, they opened their product to the full test. It fails broadly.

In the best sense of scientific measuring, a categorical evaluation of this Strategy against Project 2061 standards appears in the concluding chapter. Along with that evaluation are categorical observations on the California Science Framework's performance against the same standard.

Of all the Project's recommendations, perhaps none is as far reaching, as challenging, or as general as the call for the unification of science disciplines. Unification takes several forms in the report. It calls first for the union of science, mathematics, and technology, declaring separately that mathematics is a science. The Summary sets new curriculum goals, including "to weaken or eliminate the rigid disciplinary boundaries".

The Framework fails the NAAS tests for unification in two major ways. First, the Framework repeatedly downplays the importance of mathematics and language arts. Consider the following three citations:

> Proficiency in mathematics should not be a prerequisite to learning science. F90-p. 40

> ... the lack of specific mathematical power is not seen as an excuse or barrier to avoid exploring science concepts. F90-p. 166

and

> Comprehensive programs in English-language arts and mathematics are much broader and deeper than reading and computation tools, but at some level students need to manipulate text and numeric symbol systems in order for them to succeed in science. *The development of such tools should not be seen as prerequisite to science,* any more than they are prerequisite to literary appreciation or problem solving. [Emphasis added.] F90-p. 168

These are tragic for a guideline document. The Framework doesn't stop there. It recommends a seven point program for reducing standards in the science curriculum to accommodate limited English proficient students. (For a complete discussion of the decelerated curriculum, see the discussion on Affirmative Action Science, below.)

The failure of our educational system to convey mathematical literacy indicates that mathematics training needs changing, not that mathematics is less important. Mathematical training must be effective and relentless. As the language of science, mathematics has to be inseparable from the science curriculum.

Second, the Framework perpetuates the schism between disciplines, adding yet another field to the fray. It fails to integrate mathematics, it keeps the separate identities of physical science and life science, and it introduces earth science as a separate but equal field. In elementary school, the Framework suggests that

> physical, earth, and life sciences ... receive roughly one-third of the total class time" F90-p. 160

The intent of the Framers might have been to achieve an integration of disciplines through the thematic structure, but it fails in that objective as well. In grades 7-12, the Framework proposes (p. 165) the following partitioning of class time:

	Hours/Week by grade		
Subject	7-8	9-10	11-12
Biology	2	1	1
Chemistry	1	2	1
Physics	1	1	2
Earth Science	1	1	1
Total	5	5	5

California Science Framework Class Hours
Table 1-3

Why did they fail to accept the challenge of curricula integration? The answer seems to be that Framers work within a bureaucracy that has grown around a tradition of partitioned, independent curricula. The legislative mandate that the education system produce frameworks every seven years is a recent advent. Framing is not a full time job, but an interruption in some other sustaining profession.

The Science Framework exists within the context of a set. That set includes

Year	Framework
1978	Health
1982	Visual and Performing Arts
1985	Mathematics Framework[16]
1987	English-Language Arts
1988	History-Social Science
1989	Foreign Language

[16] A review draft dated 1991 (M91) is now in circulation.

completing the list of rice bowls for educators. The task of producing a Framework with a committee is difficult enough without doing battle with other committees over turf (or is it paddies?) Expecting the committees unilaterally to override or merge with the other subject matter frameworks is too much for even enlightened bureaucracies. Asking them to reconvene other committees may be impractical, verging on the impossible. Their work is done and the funding undoubtedly spent.

Compare the list of frameworks with Project 2061's concept of integration. The latter specifically marries Health and Mathematics to Science. It boldly specifies including social sciences in Science, going far beyond any recommendation in this Strategy. Citations from both Project 2061 and the Science Framework support a persuasive argument that language training needs more breadth and coordination with the science curricula. Communication skills is one of the specific recommendations of Project 2061, close in emphasis to themes.

Unfortunately, communication skills in schools is likely to decline under the leadership of these two documents. Project 2061 recommends enriching "ideas and thinking skills" in traditional curricula "at the expense of specialized vocabulary and memorized procedures." The Framework cautions,

> Science teachers should resist the temptation to make science a vocabulary development course. F90-p. 170

This Strategy differs. Converting a science course into a vocabulary course is, of course, some mixture of laziness and incompetence. And the common use of jargon to impress others does not promote communication. Still, a proper vocabulary is the foundation of every science discipline. It is necessary for the precision of thought and action demanded for objectivity. Vocabulary builds from year to year, reinforced through practice. A year lost in the process puts a student at least a year behind by graduation.

A student learns the meaning of words in science through experience with concepts coupled with exposure to the language. An individual who grasps the concepts of science but not the vocabulary has little future in a technological society. Conversely, an individual who finishes school with only the vocabulary of science can achieve much with a career — for example, as a salesman, a librarian, a technical administrator, an assistant, or a journalist. With the vocabulary he can enjoy reading in the disciplines, building his understanding at his own pace over the years.

This Strategy emphasizes vocabulary building in parallel with concept training. It recommends greater emphasis on phonics and etymology as the tools for lifelong building of vocabularies. The Strategy relies on a conjecture that a different part of the brain is used for vocabulary than is used to work with scientific concepts. Each of us comes with a capacity for rote learning, which like the other developmental skills will atrophy if not exercised. The only problems with vocabulary training are (1) it must not substitute for science and (2) it competes for time in the classroom. Of all the Frameworks developed in California, only one, the Visual and Performing Arts program, remains beyond the domain of a plausible, fully integrated approach for Science.

Energy Theme

No question but that energy is one of the Big Concepts of scientific thought. It is the key that unlocks the probable path of Cause and Effect. Children should come away from public school able to appreciate the energy exchanges that take place in nearly every natural or manmade phenomenon. In its most fundamental aspects, energy is thermodynamics, which the Framework discarded. Instead, the Framework at one point chooses to equate energy with power generation.

Thermodynamics. Thermodynamics belies its name; it is much more than a science of heat. This highly thematic discipline contains established laws that some like to say gives time its arrow of direction. This is a power that the Framework tries incorrectly to assign to Evolution.

Change, the most general form of evolution, is a difference in a process, involving either time or space as an independent variable. Conversely, time has no meaning absent change. Time is unidirectional because processes cannot run precisely backwards. Thermodynamic theory says that all reversible processes are idealizations and unrealizable. It does so by postulating the parameter entropy, which is disorder or unavailable energy.

Entropy is one of the Great Concepts of Western Thought. While it is difficult to teach mathematically in K-12, it is discussible and demonstrable. The Framework handles it comfortably:

> Living organisms constantly decrease their own entropy at the expense of the entropy of their surroundings. So do heat engines, crystals (as they grow out of solution) and other systems as well. F90-p. 66

The next quote uses entropy from the relatively new discipline of information science:

> As an example of entropy, consider ten pennies on a tray, all heads up. The tray is shaken; the pennies will probably settle with some heads up and some tails up. The ordered, low-entropy state (ten heads) has been transformed into a disordered, high-entropy state (some heads, some tails). Further shaking is very unlikely to produce the reverse process. But you can always produce the ten-heads state by turning over all the pennies with tails up. Doing this requires energy. F90-p. 67

Principles of entropy and the first two laws of the universal science of Thermodynamics enjoy a sort of interchangeability. Each can be derived from the other. These laws have many formulations and deep consequences for scientific thought. It relates information theory to energy. It ties equilibrium concepts to certain probability distributions, including the normal distribution familiar to the point of misuse in high school science. It is the foundation for the understanding of reversible and irreversible processes and for perpetual motion. No student should escape high school unaware of the basic ideas in thermodynamics, because they inoculate him against charlatans and a variety of scams.

Perpetual motion is the crucial characteristic of a perennial class of scams because it contradicts the first and second laws of thermodynamics. Developing the ideas of perpetual motion is an entertaining way to convey these powerful concepts for K-12. The Draft Framework presented a good formulation following a rather awkward introduction to thermodynamics:

> The study of heat can be organized around the four central principles called the laws of thermodynamics. Two of these laws are discussed in the following section. However, thermodynamics is not really a separate science with separate basic principles. ... DF89-p. 49

Continuing, the teacher could illustrate the next quote quite nicely with a class discussion of M. C. Escher's famous lithograph, "Waterfall". Here the Draft Framework had introduced two important perpetual motion machines as classified by engineers and physicists:

> Perpetual motion machines of the first kind — machines that violate the first law of thermodynamics — are impossible. An example is a water wheel that drives a pump that raises water to drive the water wheel, while the water wheel does useful work at the same time. Why is it impossible to cool a room by running a refrigerator with its door open?
>
> Perpetual motion machines of the second kind — machines that violate the second law — are impossible even if they do not violate the first law. For example, there is a huge amount of heat energy in the air. But a jet engine cannot be designed to take in air, extract heat energy from it (thus cooling it) and use the energy to propel an airplane by pushing the cooled air back into the atmosphere. DF89-p. 52

These perfectly serviceable paragraphs did not survive to the final edition.

The next quote is not accurate enough out of context of an explanation of the Second Law of Thermodynamics.

> It is possible to make heat energy flow from a cooler object to a warmer one, but only at the cost of other energy. F90-p. 67

No process exists which can make heat flow as described here. In the context of piquing students curiosity about refrigerators and the Second Law, it might be rephrased:

> "It is possible to make heat appear to flow from a cooler to a warmer object."

In the refrigerator, heat[17] flows from the cool soft drink to the colder refrigerant. The refrigerator pumps the high energy refrigerant to outside heat exchanger coils where it is expanded to raise its temperature. Heat then flows again from the warm refrigerant to the air, which is a cooler heat sink surrounding the coils. The refrigerator then does work on the refrigerant, compressing it to make it cold, while pumping it back to the soft drink. Even in the sense of a refrigerator, all heat internal to the process is from the warmer to the cooler materials.

The fact that the working fluid cools when compressed and warms when expanded is the physical property that makes it a refrigerant. Students can feel the reverse effect for themselves with a simple experiment.

> Quickly draw a large rubber band tight, placing it against the forehead. Now quickly relax the rubber band and again feel it on the forehead.
>
> Ask advanced students how they might measure the temperature changes.
>
> Let students trace through the refrigerant flow in a standard refrigerator like an opened soft drink

[17]Technically, heat is a flow of energy. The Framework should be more precise than to use the doubly redundant phrase "heat energy flow" Standard usage does permit "heat flow".

machine. Let them sense and measure the temperature at key points.

This change in temperature of a material is but one of many properties of materials that the Framework overlooks. The Framework's treatment of Physical Sciences is highly chemistry oriented, perhaps because of a strong representation on the committee by chemists. It needs to be more comprehensive. It should not only restore thermodynamics, but it should include other materials topics like hardness, plastic and elastic deformation, density, thermal expansion, thermal and electrical conductivity, solubility, structure in its many forms and states, including crystalline, amorphous, liquid, gas, solid, and plasma. The curriculum should reinforce each parameter with measurements projects.

These concepts are within the grasp of K-12 students. The editors increased the entropy of the Framework and science education by exorcising references to thermodynamics.

Interdisciplinary aspects. Contrast the following passages:

> One difference is that boundaries between traditional subject-matter categories are softened and connections are emphasized [in our treatment]. Transformations of energy, for example, occur in physical biological, and technological systems, and evolutionary change appears in stars, organisms, and societies. Project 2061:Science for All Americans, Summary: P. 5

The 1990 Framework uses the following as its only example of the interrelationships between the disciplines of physical, earth, and life sciences:

> For example, if a local business causes a toxic spill in a nearby creek, students can examine what effects toxic chemicals will have on the soil, plants, and animals of the area. F90-p. 161

Being a singular example, this view is politically supercharged. Furthermore, it is dangerous! Imagine eight graders hiking through a Love Canal to take samples! It is as insensitive as a local industry brochure that describes how it meets its community responsibilities by promising, "When a local school teacher sexually molests a student, our staff psychologists will set up counseling sessions at the school."

The real interrelationships between the disciplines are rich, varied, and unlimited, like the exchanges of energy cited above from Project 2061.

Power utility energy. What does the framework say of energy?

> All energy conversion processes have undesirable side effects. F90-p. 63.

This narrow view contains a popular misuse of the word *energy*. Here the term may be a synonym for power utilities. The framework completely misses the essential nature of its own thematic structure. It fails to comprehend its own Number One Theme, Energy. It misses the obvious opportunity to connect fundamental disciplines; and instead elects to make an unscientific, over-generalized, radical statement.

This statement is as inaccurate as a recent television show which ended by bemoaning the construction of Boulder Dam for increased energy use, the statement punctuated by shots of Las Vegas neon. The entire image was false. Las Vegas draws its energy from huge steam plants in Henderson, Nevada, not Boulder Dam. The dam was the cornerstone for flood control in Southern California as well as for Southern California growth.

The interruption in the flow of energy from the sun to its inevitable end as useless heat is the backbone of life science. The process begins with *photosynthesis*, which takes in some of the sun's energy as photons to convert water and carbon dioxide into higher energy *carbohydrate compounds* and *oxygen molecules*. Over eons, the plants created a warehouse of food and oxygen for the animal life to come, a warehouse they continue to stock. With all that chemical potential energy, the development of a life process to exploit it is not surprising. That process, *cellular respiration*, a part of metabolism in all the animals, oxidizes the carbohydrates.

This produces lower energy water and carbon dioxide, while releasing energy needed for all animal processes and activities. The animals use this energy to hunt, to love, and to slam dunk. A whole story can be woven from the disciplines to support this story thematically.

Where in this example above of the flow of energy are the Framework's "undesirable side effects"? An undesirable side effect is a bureaucracy that fails to teach about energy.

Potential energy. The Framework also has a thematic problem with potential energy.

> Because there are two fundamental ways in which a system can change, there are two basic types of energy. A system can change when the distance between the parts of a system change or the parts are rearranged. Energy associated with these kinds of changes is traditionally called potential energy. F90-p. 62

> It is unfortunate that the term "potential energy" is used to describe a type of energy because of position. Kinetic energy has just as much ability to be converted into another form as does potential energy. Many persons have developed misconceptions regarding energy because of the use of this term. F90-P63.

> The molecules of any substance are in constant disordered, random motion. Heat energy is the total kinetic and potential energy of the disordered motion of the molecules of the substance. F90-p. 65

> Heat energy is the total kinetic and potential energy of the random motions of the particles of a substance. F90-p. 62

There are as many fundamental ways to change a system as there are to define it or its energy state. Some authors define energy by the storage method, such as potential, kinetic, thermal, chemical, and electrochemical. Some define energy as mechanical, electrical, and heat, and some include heat as a mechanical energy. Some define nuclear energy in a way that gives it a potential energy component.

Rearranging the parts of a system usually takes work, which is energy; it need not affect the potential energy of the system at all. In general, potential energy refers to energy stored by virtue of a relative position of an attractant in a *field*. The primary examples are a gravitational field and an electrical field, where the attractant is a mass and a charged particle, respectively. The energy in a chemical bond may be of the same type. Physicists extend the notion to spring extension and compression. Temperature is the mechanical kinetic energy in the random motion of particles. Heat is a flow of energy and has no potential energy component in any sense.

Atomic energy. The following quote is surely a typographic error,

> [Students] should be aware that there are many natural sources of radioactivity to which the biosphere has been exposed since earliest times and that nuclear reactors are known to have existed in nature. F90-p.47

but then

> ... there are forces within the earth, fueled by nuclear reactions with the mantle and core ... F90-p. 29

Really? Is it fusion, fission, or decay? Radioactive decay is well-known within the earth, but what are the forces released by decay?

Stability Theme

Stability is a highly valued and essential concept in science. It says something about what a system does following a disturbance, where some reasonable bounds are placed on the size of the disturbance. Many systems are stable, but only within bounds. The Tacoma Narrows Bridge[18] and the

[18] Failed on November 7, 1940. The movies are great for the classroom to illustrate resonance or conditional stability followed by destructive instability.

double-decked Chester Nimitz Freeway[19] could not be knocked over by a whole third grade class with hammers.

If a system always returns to the state that it was in before a disturbance, it is stable. The concept of stability opens up a wealth of concepts about dynamics of systems, and leads to the important notions of conditional stability, and instability. The Tacoma Narrows Bridge was stable until the wind picked up. Then it began to resonate or vibrate, twisting and oscillating in a state of conditional stability. When the wind increased to just over 40 knots, the motion became unstable, increasing in amplitude until the whole structure collapsed.

The Framework struggles with this theme, saying incorrectly

> Stability refers to constancy; that is, the ways in which systems do not change and why. F90-p. 32

and equally off the mark,

> Stability is related to the idea that nature is predictable. Given a set of initial experimental conditions, results are expected to be replicable. Indeed, failure to obtain reproducibility begins an immediate search for uncontrolled variables. Science is based on observations and set in a testable framework of ideas. Scientific theories and laws usually remain fairly stable because they are based on consistent evidence. F90-p. 32

Stability is not a synonym for steady state or for equilibrium. And stability has little to do with predictability. A far better connection lies between Patterns and predictability. Science has no principle that its theories and laws "usually remain fairly stable". The intent of the author exactly reverses the Cause & Effect principle. Nature provides man with objects and processes that exhibit patterns, not necessarily stability. Scientists extract the patterns to describe them in models.

Stability is a critically important concept in modeling the earth's environment. The Delicate Blue Planet is poetic

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[19]Interstate 880 through Oakland, California, collapsed in the San Francisco earthquake at the opening of the 1989 World Series.

imagery, but it is not science. One can postulate with greater force of scientific experience that the Earth exists in a strongly stable state. But to understand this, one must have a grasp of equilibrium or stability and *non-linear*[20] systems, ideas that should be developed over the entire K-12 experience. The abundant heat capacity of the oceans governs the temperature of the atmosphere. Heat is exchanged with the atmosphere through the water, oxygen, and nitrogen cycles, and through the most important dynamics of storm systems. Where does N2 come from in the atmosphere? Why is it 78%? What is the Nitrogen cycle? How does methane (CH2n) fit in? Is there a more general model for the atmosphere? The exchange of material and heat principally between the ocean and the atmosphere is a good model for the concept of equilibrium. Except for the well-publicized increase in carbon dioxide, the net exchange is approximately zero at present and within the resolution of our observations. Carbon dioxide is increasing, but the change is so small that atmospheric scientists cannot as yet determine the cause and can only speculate about the effect. As far as anyone knows, it could be caused by man, a change in nature, or be part of a natural cycle in nature.

Any model that contains environmental parameters in an unstable state should be immediately suspect! It is as improbable as coming upon a cone in nature balanced on its

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[20] A linear system has the following property: If it has a certain response to one stimulus, and a different response to another stimulus, then its response to both stimuli at once will be the sum of both responses. A scale in a supermarket has this characteristic, but only approximately! A cheap scale makes a good subject for classroom calibration. The idea that a system has limits to its linear range can be brought home by weighing a feather, or asking students what would happen if they put an elephant on their family bathroom scale. A though experiment is sufficient here. A non-linear system is any system which does not have the linear property. An excellent example of a non-linear response is the counter on a VCR. Ask students to calibrate the counter against recording time!

apex. Scientists speak mathematically about a point in a continuum as having zero probability[21]. Where a system or model requires an exact balance, it is too improbable to be credible. If man can disrupt the atmosphere by his puny burning of fossil fuels , then the atmosphere is marginally stable. This might even extend to his releasing of CFCs. Why didn't small natural variations, like changes in solar radiation or volcanic activity drive the atmosphere into some other, more stabile state long ago?

Clichés about the "balance of nature" are but more misleading imagery. No such reference should be taught in any sense as fact in the science class. It belongs in every science curriculum, but as a conjecture for study and discussion. It is a model for a system that is stable, but which can be easily upset, meaning made at least temporarily unstable by a small disturbance. It fails to take into account the forces of equilibrium that cause many systems in nature to move gradually along stable pathways. This includes the relative populations of plants and animals and the composition of gasses in the atmosphere.

Stability usually has a cause, as when a system has reached maximum entropy or when it is under the influence of a controlling parameter. A system may be stable because of feedback which produces a restoring error signal. This observation opens the door to the whole new, modern discipline of study called control systems.

Models Theme

Project 2061 in its recommendations for themes, places models in second place, saying

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[21]Continuum is a fancy word for not having discrete states, like On and Off, or 0 and 1, but everything in between. The reference to zero probability is the same as saying the chance of a real number selected between, say, 0 and 10 being π or 2.3 or any other specific real number in the span, is zero.

> These include the idea ... of models as physical devices, drawings, equations, computer programs, or mental images that suggest how things work or might work

The California Science Framework purposefully avoids referring to models in Science (compare the two quotes at the end of this chapter). The omission demonstrates a lack of understanding of what models are and their role in science. In part, the problem may be semantic, for the Framers are inconsistent in their meanings of key words like model and random. The practice of science demands precision in language, and the Framework should set the tone as a model for that dictate.

A model starts with definitions, made as precise as necessary and possible. From there, it proceeds like mathematics, bound to follow the precepts of logic. The definitions are a direct link in the chain that connects the model to the Real World. A model with weak definitions might make remarkable predictions, but the conditions under which the predictions might come to pass might be impossible to achieve.

The Framework should have developed the concept of models, defining in the process the ideas of principles, conjectures, hypotheses, theories, and laws. What is the tyro supposed to think of "Newton's Laws", the "Four Laws of Thermodynamics" and "Heisenberg Uncertainty Principle"? The range of science needs a definition that includes these concepts. This would help the framers place their defense of theories in a proper light.

At one time, the Draft Framework took a step in the right direction on models. The 1990 Framework left this quote on the cutting room floor:

> Computer models are powerful tools, but students should distinguish between models (with their assumptions and simplifications) and the real objects that comprise (sic)[22] the universe. DF89-p. 75

[22]The intended word here is compose, not comprise.

Students need to learn the distinction between real world objects, also known as reality, and models in general. The deleted caveat that this distinction applies only to computer models is inappropriate. A computer model is actually nothing but a math model! A complex concept like the physical structure of a double helix molecule becomes a math model when the scientist creates a computer image of it. However, a good case exists for making a distinction between computer models and other models.

Man finds himself forever isolated from real objects in the universe by his senses, his perception system, and by the limitations of his scientific concepts. Scientific descriptions of the Sun, for example, are only models even if no more than prose. Moreover of all the models for the sun, a computer model in some laboratory somewhere in the world is likely to be the most useful of all such models. To make matters worse, the scientific models of the sun are unstable. A small change in temperature causes the model of the sun to collapse or expand rapidly. Astrophysicists need a model that has a broad region of stability around the known state of the sun.

We don't even have to reach beyond Earth for such examples. Scientific models for the core and mantle of the Earth and for climate are still in flux, aided by computers where our analytical techniques are woefully inadequate.

The computer is invaluable in solving complex, non-linear problems like these. Scientists have yet to make real strides into the non-linear world analytically. Man's models through the 20th Century are dominantly linear. Because so much of the real world appears non-linear, we can say that scientific models are predominantly first order. This means that higher order behavior in the models is often simply missing. Non-linear computations can be incredibly complex, and many such basic computations remain unsolved problems.

The danger in computer models is two-fold:

> Frequently people place faith in a model because the results came out of a computer; and

> A model run on a computer can easily mask incomplete or erroneous science.

The scientist may not have done sufficient analysis on the underlying math model. He may not have provided independent checks and balances in his computer model. People can invent computer models at a prodigious rate; validating them and providing some kind of closure is a different matter. Getting a computer program to run can be a trying experience. Once it begins to produce reasonable results, it is likely to convey an unjustified sense of victory. The scientist is obligated to validate computer models with as much vigor as all other models. If the models are to do more than calculate, they must have predictive value and reliability!

All too few student head for careers in science. The science education program must rely on a mission statement to improve the science literacy of the public at large. The Framework's call for SI metric conversion is a poor alternative, designed for some idealized educational principle:

> In dealing with energy and power quantitatively or semiquantitatively, give preference to SI metric units: the joule, the watt, and their multiples. Students who have familiarity with U. S. customary units (e.g., the foot-pound, BTU, and horsepower) should be encouraged to learn how to convert to SI metric. Other units of energy sometimes used are the kilowatt-hour and the kilocalorie. The use of these units is discouraged by international convention and is slowly dying out. F90-p. 63

The well-trained scientist will convert from one unit system to another with ease. The process of making conversions and dealing with the algebra of units and dimensions needs to replace any dogmatic unit system indoctrination. A citizen with minimum science literacy will be able to compare energy usage from his gas bill measured in BTUs with his electric bill quoted in kilowatt-hours. He will have forgotten that a BTU per second is dimensionally equivalent to horsepower and foot-pounds, but he will be able to find the conversion factors and use them. He will be able to understand the thermodynamic efficiency of his appliances in various units.

Similarly, stating the speed of sound in meters per second alone impedes the child's ability to calculate the distance to lightning in familiar U. S. units. (The speed is approximately 1/5 mile per second.) Again, the preferred method is computational skill with mixed units.

The Framework compounds the problems with

> Joule's (pronounced Jowell's) law ... F90-p. 71

Even if correct, this is too pedantic.

MISCELLANY

Conventional Notation

Equations have a certain permitted grammar, much like natural language but not quite as varied. Typically an equation reads like the English sentence it represents, with the subject on the left hand side, although symmetry in the expression often suggests a different form. When the expression on the left is complex, as in a multinomial or differential equation, the right hand side often designates a state value or governing condition. We are taught in Algebra 1 that presented with $x + 2 = 3$, we should solve for x, and perform the process of writing $x = 3 - 2$ and, therefore, $x = 1$. We are taught that a straight line is represented by

$$y = mx + b.$$

But

$$\begin{aligned} y - mx &= b, \\ mx + b &= y, \\ mx &= y - b, \text{ and} \\ y - mx - b &= 0 \end{aligned}$$

are all equivalent. They find uses in different applications, sometimes suggesting slightly different methodologies or origins.

A straightforward way to express the dependence of a parameter is to make it the subject of a sentence. In science, the dependent parameter is typically the more complex or the inferred parameter. Often the equation is a formula, a recipe for a method of computation, an equivalence, or a representation of a parameter on its governing variables.

These ideas are rather weak conventions. A rearrangement of a conventional equation following well-known rules for their manipulation always produces a correct variant of the equation. One could always contrive a thought process that justifies a different collection of variables on one side of the equation or the other. Nonetheless, the following two examples from the Framework are discordant. They are unwarranted inversions, standing alone as they do without any justification for the peculiar forms.

> The speed of light is related to its frequency (f) and its wavelength (λ); the relation is $f = c\lambda$. F90-p. 74

and

> As with all waves, the speed v of sound is the product of the frequency f and the wavelength L: $v = fL$. DF89-p. 64

These two sentences imply and the equations reinforce that a wave's velocity is the dependent variable. It might appear to the novice that one could vary the frequency of a signal, keeping its wavelength constant, and cause a change in the velocity of propagation. This is decidedly incorrect. The fundamental parameters that science measures are wavelength and speed of propagation. Physicists infer frequency. They can measure its effects, but frequency is the more difficult and the more abstract parameter. It is the derived parameter from scientific models, best expressed as the dependent variable. Specifically,

$$f = \frac{c}{\lambda}$$

and

$$f = \frac{v}{\lambda}$$

Cause & Effect

The concept of dependent and independent variables is a close relative of Cause & Effect, which the Framework manages to bungle from place to place. Science frequently applies the Principle of Cause & Effect, and usually tacitly. Modeling is an attempt to fix causative conditions from which a particular effect, a predictable event, will ensue. Usually the relationship involves the direct, traceable transfer of energy. Examples are the release of potential energy as in a volcanic eruption or an earthquake. These are perfectly analogous to the cliché, "breaking a log jam". Another type of model accounts for forces and energy that change an object's momentum. The assumption of the Principle is validated when the model proves to have predictive power.

Consider the following three passages excised from the Draft Framework in the light of Cause and Effect.

> It is very important for students to understand that tectonic processes stimulated by the pressures of the Earth's rotation are the basis for the circulation of ocean waters and the water cycle. Without these tectonic processes, the Earth would lose its force field and then its atmosphere. DF89-p. 83

The next must come from the same author:

> This [water] cycle can continue because the Earth's force field, caused by tectonic processes within the Earth, holds the atmosphere on the planet. DF89-p. 84

and still later

> Water in the oceans moves because the Earth is always moving. DF89-p. 87

How might pressures of the Earth's rotation stimulate tectonic processes? Geologists know that the Earth does not rotate exactly as a solid body, but why not? Today, the consensus seems to be that the primary cause for tectonic processes is convection caused by thermal gradients that alter solid body rotation. The Earth's daily rotation affects but not effects tectonic processes.

How might tectonic processes couple into the much, much faster ocean currents? What might the process be that could gear up the grinding of tectonic plates to create ocean currents of several knots?

Certainly circulation of the oceans has a profound effect on the Earth's weather system, and without that circulation the water cycle might be drastically different. However, the water cycle from the oceans, to the atmosphere, to precipitation, to surface storage, and run-off back to the oceans is primarily the result of the convection of solar heating. (Students should also learn that convection is the result of differential densities, requiring a force field like gravity, and that the heating causes the density changes.)

What is the force field caused by tectonic processes? Earth scientists attribute the magnetic field to motion in the iron core, which has no effect on the atmosphere. The gravity field is due to mass alone, of which the plates in the tectonic process are quite minor.

How does the motion of the earth effect motion in the Earth's oceans? The origin of this kinetic energy is thermal, which the Earth's rotation shapes. Rotation affects surface temperature gradients, but it reduces them by dissipating them! The Coriolis effect is a coupling of the Earth's rotation with an object's velocity. It does not cause that velocity, but turns it.

The Framework attributes cloud motion to the Earth's rotation in another strange, simplistic way:

> Because the Earth constantly rotates, these clouds circulate over the land surfaces in patterns that are affected by the topography of local regions. F90-p. 99

The Framework has created a doubly hypothecated and confusing sentence. A student might conclude that the Earth's rotation exerts some kind of accelerating or retarding force on the atmosphere, a friction-like force that causes clouds to circulate. That force would require that space exert a frictional drag against the atmosphere. The existence of that drag is a subject of scientific speculation today, but it is not a dominant factor in atmospheric dynamics.

Two main thermal energy sources provide the best models for the driving engines of the atmosphere. One is solar, the other kinetic. Direct solar heating causes a convection toward the poles from the equator. The atmosphere and the surface of the Earth exchange energy through three large vertical circulation systems or cells. Even more energy is added when cyclonic systems transport heat and moisture from the tropical oceans into the atmosphere and toward the poles.

The Earth's rotation couples into the motion of the atmosphere through the Coriolis Effect. This force bends the flow of air at right angles to the pressure gradients of the thermal flows. Clouds are then carried with the local air masses. Local topography affects air circulation in several ways, most particularly as in rising land causing updrafts as the air mass passes (orographic lifting), water contributing heat or moisture, and dark areas heating more than light areas.

The models with the greatest predictive power today place solar heating as the primary engine, the Cause, in the dynamics of the atmosphere, the Effect. That engine works indirectly through heating of the surface and the oceans to cause vertical flow. The Earth's rotation then shapes the resulting movement.

A similar Cause & Effect disconnect occurs in the Framework's treatment of ocean currents:

> Water also circulates because the earth rotates, and the force of this rotation causes movement of surface water. F90-p. 103

The Framework makes amends when it says,

> Waters circulate primarily because of winds and solar heating. The direction that these currents follow is caused by the earth's rotation. F90-p. 104

On the other hand, the Framework misses the Cause & Effect relationship in a different way when it says,

> According to the theory of relativity, the speed of light in a vacuum is known to be exactly the same for all observers. F90-p. 147[23]

Einstein posed the theory of relativity on the heels of puzzling data showing that the speed of light was a constant![24]. Having a constant velocity implied that light waves propagated absent a medium. Physicists had no model for propagation of waves without a medium, so they postulated the ether. This ether had the property of existing throughout space; earth, they suggested, traveled through it. The Michelson-Morley experiment sought to measure the effects of the earth's motion through the ether. The ether theory was invalidated, and once again the velocity of light was constant in all directions through space. The constancy of the speed of light in vacuum was rapidly becoming a fact.

Physicists speculated that Einstein's special theory of relativity relied on the Michelson-Morley experiments, but he denied it. His space-time transformations in the special theory of relativity indeed have the speed of light constant. But his transformations were formulated earlier by Lorentz, and so they have the name Einstein-Lorentz transformations. Going back one step further, the Lorentz transformations are implied by Maxwell's differential equations for electric and magnetic fields, a model well on its way at the time to achieving the status of law. Einstein's inspiration for both the special and general theories of relativity came from a need he perceived to make physical laws, like Maxwell's, invariant when cast in different coordinate systems.

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[23]The Framework is more accurate when it says earlier, "The speed of light is exactly the same for all observers. This statement is one of the fundamental principles of the theory of relativity." (F90-P. 74) This statement would be improved by replacing principle with fact, but it passes without being too pedantic.

[24]"The realization that the speed of propagation of signals has a finite upper limit led to the development of relativity theory." (B85), P. 561

Einstein recognized that like the theories themselves, the coordinate systems are man's constructs and laws should not depend upon an arbitrary frame of reference. His theories not only had to be consistent with the facts, Einstein was expanding the domain of consistency.

The Michelson-Morley experiment isn't necessary to deny the ether theory. The ether was a concocted entity, hypothesized to provide a medium for light waves. It had scientific legitimacy as a conjecture. The Scientific Method does not allow untestable, unmeasurable entities in theories, and the famous experiment satisfied the scientific imperative. This was a case in which validation and theory appeared nearly simultaneously, which is not a problem. The Scientific Method as defined in this Strategy is explicitly not a time sequence of events.

All experiments with light show that its speed in vacuum is constant. Whether this is confirming of the theory of relativity or validates a prediction of that theory is somewhat a subjective preference. Science knows the speed of light in vacuum to be exactly the same for all observers because of observations and measurements. It is not the result of Uniformitarianism. This fact is consistent with the theory of relativity by the way that Einstein created that model. The theory of relativity logically follows from the data, not the reverse.

A similar problem arose in the Draft Framework's Cause & Effect view of Newtonian mechanics:

> According to Newton's theory, momentum is directly proportional to both mass and speed. DF89-p. 123

Physics defines momentum that way! The Framework's statement might lead a student to conclude that a discovery or theory exists where a definition belongs.[25]

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[25]This was modified in the final version by dropping, "According to Newton's theory," but this only makes the problem implicit rather

Measuring the Framework by Framework Guidelines

The 1990 Framework provides teachers and text book writers with principles of good science for them to use as guidelines for education. How does the Framework stack up against these same criteria?

Trite Terminology. Surely every writer has pet words on his hit list. The Framework cautions against the word *special*.

> A third kind of corruptive euphemism involves what might be called *special* science. Frequently, one encounters a passage in a textbook such as, "Desalination of seawater is done with special equipment," with no further explanation.

Other vacuous words include *very* and, except in a statistical sense, *significantly*. The Framers err by using *carefully*, and not just for stylistic preferences. It is empty hyperbole, used in much the same sense as *special*. They should ration themselves to exactly one usage of this terrible word, and teachers should never use it in science training. This word is objectionable because it implies that other scientific work is done less than carefully.

Scientific Method. Under the heading,

> The character of science must be represented faithfully. This means it must be shown as open to inquiry, open to controversy, and nondogmatic by its nature. F90-p. 206,

the Framework says:

> (a) *The Nature of Science*. ... The scientific method is not a monolithic formula that can be reduced to hypothesis-materials-methods-observations-conclusions. Instead, examples of how scientists investigate problems — examples that delineate the processes, successes, and limitations of science — should appear in every chapter.

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than explicit. Momentum is a manmade concept, not directly observable in nature.

There is no further mention of scientific method in the main body of the Framework! It limits the meaning of *method* by suggesting that it is the *how* of scientific investigations rather than the *what*. The Framework says here what "the scientific method is not" and nowhere says what it is.

Controversy and Ethics. The Framework continues on controversy and ethics in science:

> b) *Controversy in Science.* Instructional materials should encourage responsible, science-based discussion of controversial or contentious issues. Science should be portrayed as a vital, changing endeavor with controversy and competing lines of intellectual discussion ...

The Framework fails this test in three major ways. First, it is guilty of unscientific, inflammatory excesses on evolution which damage an understanding of all science. Second, it would indoctrinate children with unsubstantiated beliefs under the banner of conservation, human annihilation of species, and energy.

Third, the Framework links instruction in ethics particularly and exclusively to science. Ethical conduct is scarce in the U. S. today — among Congressmen and other public officials, among police and the anti-police, among the press, in financial institutions, on campuses, and in trades and industry. The Strategy commends the school system for encouraging debates on ethics.

The necessity for ethics in a profession is proportional to the degree of public trust involved. All work of elected officials involves public trust — educators have our children entrusted to them, the people entrust their security to police and armed forces, financial institutions have our money, and physicians have our lives in their trusted hands. The First Amendment guarantee of freedom of the press is not a license for journalists, but the right of individual citizens to publish, a public trust delegated to the institution of the press. A public trust befalls scientists who use their reputations to advocate causes in the media, but this is not Science.

All children need training in ethical behavior, but the science curriculum is the least appropriate place for three reasons. First is that while some of science involves public trust, a much greater proportion lies in other professions. It is not particularly or peculiarly a science problem. Second, the amount of time devoted to science education is too small for ethics training. Third, too few children receive anything but a perfunctory science education and so would miss out on any ethics training at all.

Dogmatism and Integrated Curricula.

> Nothing in science should be taught dogmatically. F90-p. 206

> ... science should be explicitly integrated with other disciplines, especially the linguistic, historical, and mathematical fields. It should not be seen as an isolated discipline estranged from other fields of inquiry, such as the arts and health.

The 1990 Science Framework perpetuates the dogmatic separation of education into traditional fields. It has relinquished language, logic, and mathematics to other curricula. It doesn't just perpetuate the division of science between physical and life sciences, but adds yet another special interest, earth sciences. It shifts the balance of instruction arbitrarily and contrary to any measure of importance for the subject matter. If one were to use jobs, public issues, or intellectual development as measures for distributing the instructional time, the results would be quite different.

> The etymology of scientific words, the accounts made by scientists of their own discoveries and of their times, and the applications of mathematics and of numerical organization of information to scientific investigations are all examples of vitally important features of a good science curriculum. F90-p. 207

None of these important topics appear in the main body of the Framework.

Objectivity and Measuring. The Framework completely misses the idea of measurements in science on several opportunities. Here is one quote of interest:

> When we say that all science is based on observations, we mean that we use the evidence of our senses (seeing, feeling, hearing, and so forth) to obtain the information on which scientific work is based. Even when we use an instrument to detect and measure things too small to be seen with an optical microscope, the output of the instrument must feed into one of our senses before we can interpret the data that it supplies.
>
> When our observations of a phenomenon have been confirmed or found to be repeatable, such observations become fact. However, even though there is little doubt about the observation, it cannot be accepted as an absolute certainty without experimental confirmation. F90-p. 16

Even though the Framework often acknowledges the mental act of comparing, it fails to place comparing with standards in the sequence of scientific procedure.

Affirmative Action Science

Affirmative Action, the big social experiment of the last quarter century, continues its migration into science education, evidenced by the 1990 California Science Framework.

Affirmative Action Heroes of Science? The Framework recognizes just two scientists for special biographies. Among all the scientists who have contributed to the great ideas of science and humanity, which Project 2061 lauds, only two relatively obscure American figures, one female[26] and one black[27], get special treatment. These may be fine, cultured, admirable people in their own rights, but they are far, far down the list of contributors to science.

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[26]Maria Mitchell, 1818-1889, discovered comet, Vassar professor.

[27]Perch L. Julian, 1899-1975, 'the soybean chemist', invented economical production of cortisone, synthetic hormones.

What is a role model supposed to be? Have the people set a national goal to provide every black and female child with the expectation of a handout? Or, do we want them to understand and value, if not emulate, the deeds of the contributors to Western thought? Which is the national goal, for the young to (a) contribute regardless of race or gender, or (b) receive recognition for their race or gender? Moreover, even if it is deemed necessary to highlight minority or female scientists, might it not have been better to select individuals who contributed more to science, as for example, Marie Curie and Booker T. Washington? Wouldn't the effect be greater if these people were listed with the giants of Science and mathematics? Having two obscure figures replace the whole list of people who have created science and mathematics politicizes the teaching of science.

Affirmative Action Pigeon English? On language training, the Framework says

> The important task of modifying science instruction to remove barriers to comprehension will have to be met by all teachers of science, not only those trained for ESL [English as a Second Language] or bilingual programs. These teachers have within their teaching repertoire strategies that can be used to lower the linguistic barriers preventing access to their disciplines. F90-p. 170.

Who hasn't known immigrants who came to the U. S. as adults, refusing to even try to learn English? The stereotypes are familiar — the Grandma speaking Chinese, Gaelic, German, Japanese, Italian, Polish, or Spanish, confined to her home and family for life. One small child in her family soon becomes the multilingual family translator.

A child learning a foreign language, or even American sign language, at home can become not only proficient in English but accent free. Somewhere along the line, though, the mind starts closing to language. At some age, proficiency begins to flag. Beyond some point, the accent will usually persist for a life time. Later still, the only remnant of the training is a faint memory of the vocabulary.

The Framework speaks of Communication Skills, but receptiveness to Language is a stronger concept. The young brain is especially receptive to language, and for the sake of the child the curricula must not compromise the opportunity in the first three to six years of grade school.

Depriving a child of a science education disenfranchises him from jobs and citizenship. A child deprived of English in the U. S., though, is worse off. The greatest barrier to success in Science or to even a job in the U. S. is poor command of the language. English Literacy must take precedence over all other instruction. Education rests on language. English is the international language of science and technology. English is the international language of commerce. ESL errs, favoring other subject matter and vague and empty concepts of reaching out, social adjustment self-actualization, or self-esteem in place of science, technology, and commerce!

The Framework says science can be a vehicle for other arts — instead language is the vehicle for science!

> Scientific literacy could receive a considerable boost if science were used as a vehicle to enhance reading, mathematics, and the arts. The use of science to teach other fields has been shown to be quite successful in many exemplary elementary science programs. F90-p. 161

The Framework is pleading with the other disciplines, "Please, won't you help us teach some science?" The strategy for science education cannot be to sneak in some science in a science-starved education program! Language is the foundation of science and mathematics. Science is the objective part of all fields of knowledge.

English as a Second Language, along with bilingual education, is a moral disaster! One can believe in bilingual education, if it means teach the Gringos Spanish. Then they will be able to converse with their underrepresented house servants or with their functionally illiterate laborers in the workplace! An Affirmative Action program that gives other subjects precedence over language promotes and perpetuates second class citizenship.

The best affirmative action program would be to select children from ages 3 through 10 or so who are learning Spanish or non-standard English at home. These are the members of the targeted minorities in need. Then, occupy them *full time* in English training — Summers and Winters, after school hours and week ends, eight hours a day. Immerse them in English in a special education program. Combine the program with day care centers and project Head Start. Select subject matter for the daily lessons from various fields of study, but grade them solely on language acquisition. It wouldn't take too long for an average child to come up to standards! In fact, many would have an advantage, being bilingual.

Affirmative Action Decelerated Science? Taken out of context, elements of the following seven point program are difficult to fault. But taken in context, educators will hear a clarion call to slow down instruction and remove content from an already inadequate program.

TEACHING SCIENCE TO LIMITED-ENGLISH PROFICIENT (LEP) STUDENTS

> We are not to create two science curricula. ... Using techniques founded in sound teaching practices, teachers should:
>
> 1. Simplify the input.
>
> Use a slower but natural speech rate with clear enunciation. A modified, controlled vocabulary may be appropriate. Science teachers should resist the temptation to make science a vocabulary development course. Use proper science terms when necessary, but avoid obfuscation. Do make attempts to restate, redefine, provide familiar examples, and draw on students' prior backgrounds. Define words with multiple meanings and avoid the use of idiomatic speech.

Translation: Slow down instruction, minimize technical language.

2. Provide context clues.

Be animated, use gestures, and when possible act out the meaning. Use props, graphs, visuals, and real objects. Hold up the mortar and pestle and demonstrate how to grind leaves in preparation for extracting chlorophyll. Make frequent visual and word associations. Show students the finished product when possible.

Translation: Slow down instruction by acting out words.

3. Draw on prior background.

Have students brainstorm, list things they already know about the topic at hand, and be prepared for and accept single word or limited responses. Categorize their responses to show associations and relationships. Use graphic organizers, such as chapter or concept maps. Provide multisensory activities and ask open-ended questions to elicit a variety of responses and record the students' responses when possible.

Translation: Lower standards by asking for less articulate responses.

4. Work to ensure understanding.

Repeat ideas or concepts frequently. Expand, restate, and reinforce important points. Do regular comprehension checks to confirm that students really understand the concept under investigation. Frequent interaction between teachers and students and among students are strategies, along with others, for formative evaluation.

Translation: Slow down instruction by using more repetition.

5. Make sure instruction is content-driven.

Identify a few key concepts. Attempt to ensure understanding of fewer, larger ideas rather than many factoids, those isolated facts and definitions that have long dominated science instruction. Make sure those few concepts are learned well rather than many ideas developed superficially. Select essential vocabulary, about five to seven words, but certainly not 20 or 30 per chapter. Teach the selected vocabulary through a variety of interactive ways (avoid simply assigning them to be defined). Explain textual features such as bold print, italics, and chapter summaries in order to use context clues in the text, such as pictures, graphs, tables, flow charts, and similar graphic materials.

Translation: Slow down instruction by using fewer concepts.

6. Ensure that instruction is student-centered.

Use a variety of grouping strategies, such as small-group, large-group, and cooperative learning. Provide instruction with direct experiences — about 40 percent of instructional time — which are appropriate to various learning modes. As much as possible, put materials in students hands; demonstrations are not as effective as manipulation. Provide opportunities for students to *use* concepts rather than merely reiterate the concept label and definition.

Translation: Slow down instruction. Let student demonstrations set the pace.

7. Use science text effectively.

When using text materials, begin by establishing students' prior background and be prepared to add background when necessary. Select the essential vocabulary and teach it through a variety of interactive and contextual ways that capitalize on prior experience. Begin a chapter with an activity; try starting with the first laboratory activity even if it is located three or four pages into the chapter.

Translation: Slow down instruction by gearing instruction to the multicultural background of the students.

All students in California deserve access to high-quality science instruction. Using techniques to reduce linguistic barriers will ensure access for students with limited-English proficiency. Rather than trying merely to *cover* the content, we should *uncover* science content. F90-p. 170-171

Quotables from the Framework

All the earmarks of the committee work are there in the Framework. The unevenness means that it has some quotable passages, some with special strategic value. First, here are a few quotes with a light-hearted tone.

Comic relief.

> Astronomers put their observing instruments where they can see best. [Evolution, Scale & Structure] F90-p. 88

Is that where the sun don't shine?

> Most astronomers work at learning as much as possible about the objects they are studying—their size, mass, shape, composition, temperature, and other conditions. [Evolution, Scale & Structure] F90-p. 88

> The process of planned observation, theory building, prediction on the basis of theory, and further observation characterizes the scientific practice of astronomy. [Systems & Interactions] F90-p. 89

Clearly astronomy is where science is practiced! And just think what you could learn:

> When the sun is up, it is daytime; daylight comes from the sun. When the sun is down, it is nighttime, and the stars can be seen. The sun provides heat as well as light; it is usually warmer during the day than at night. The moon may be visible in the daytime or the nighttime. [Patterns of Change] F90-p. 79

> The earth is warmed by heat from the sun. It is usually warmer in the daytime than at night. It is usually warmer in summer than in winter. The earth is not so close to the sun that we boil, nor so far from the sun that we freeze. [Patterns of Change] F90-p. 106

This staggers the imagination even for K-3! How can a five year old keep apace?! Is this the new approach to multicultural training? And see how the themes fit right in!

But seriously folks, ... In definitions of this Strategy, technology and basic research are part of the one field of knowledge, Science. The Framework recognizes the strategic ties between technology and basic science in this laudable quote:

> *Technology is based on fundamental science.*
>
> An understanding of the principles and practice of sciences is essential. This understanding will enable students to cope successfully with the world they will inherit — a world about which we can predict but little[28]. Much of modern science is based on technological development, largely in instrumentation[29]. Educators have the chance to prepare students for the technology of the future by helping them to develop a deeper knowledge of basic science, and how science works. We cannot expect our democratic society to make intelligent decisions about science, technology, and public policy unless its citizens are scientifically literate. F90-p. 13

and

> In a technologically advanced culture, the scientifically illiterate are disallowed entry into educational, economic and political arenas. F90-p. 167

The Draft Framework used the word *disenfranchised* instead of *disallowed*. Yet disenfranchisement is the consequence for the scientifically illiterate. They will find major economic sectors of our society closed to them. They will find their potential for job advancement sharply curtailed. They are suckers for political charlatans and con men. They are incomplete as citizens. Disenfranchisement is the definitive word. We live in a society where the important issues of the day are dominantly founded in science and technology. Solutions do not arise from belief systems, or a romantic return to simpler times. Technology is knowledge and it grows irreversibly.

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[28]Although, predictions are the validation of all science comprising all its power.

[29]Plus computers and remote access through vehicles and sensing.

The goal of science education must be to create a science-literate public. A primary objective is to exploit the love of knowledge and the fascination with science in our youth, casting science in its proper framework as a formidable branch of knowledge. Knowledge is power, for individuals, for nations, and for economies. Educators need to deflect the concept that science training is for budding scientists alone, and that they are going to make scientists of all the students. They need to restructure the current K-12 program which instead of exploiting native interest in science manages to beat it out of the students.

Coping with Change. Students learning science and juries deciding technical issues carry with them the mental baggage of belief systems that cannot be a part of the realm of science. A goal of science training is to raise these notions from other fields of thought to the conscious level. There they support rather than interfere with objective thought. Science must establish each fact for itself through observation and measurements. The Framework does a respectable job of preparing students to accept change as fact:

> The earth's surface is constantly changing. Through time, many different kinds of plants and animals have lived on the face of the earth, and most of these are now extinct. F90-p. 95

What science measures is not a brief glimpse of a cataclysm; systems pass through stable states of long duration. The scientist learns to seek patterns in the processes to account for causes of change as well as causes of stability. Each model in science expresses a pattern within an implicit or explicit scale of observation in time or space. The next citation is excellent, and to the point:

> Ecological theory is concerned with the study of natural systems. The balance of nature is in fact a shifting balance in which nothing is constant but change. A human lifetime sees only glimpses of the vast scale of this change. There are many patterns: seasonal, reproductive, and populational cycles; migrations in and

> out of populations (which themselves wink in and out of existence); and extinctions. F90-p. 136

Precision in Thought. Scientific models are descriptions of objects and relationships based on the most complete set of Real World facts available. The scientific process adds precision to the descriptive language by extracting its logic and mathematics. Two keys to language are phonics and the structure of words themselves. As the Framework says,

> The etymology of scientific words, the accounts made by scientists of their own discoveries and of their times, and the applications of mathematics and of numeric organization of information to scientific investigations are all examples of vitally important features of a good science curriculum. F90-p. 207

In this Strategy for science, language and mathematics arts are the foundation of the Scientific Method.

> We cannot experiment directly with galaxies, black holes, quasars, or quarks, but we still know a great deal about them. Scientific descriptions of relationships are always based upon the logical arguments that encompass *all the data* on hand. F90-p. 150

The emphasis is to point out that science does not allow subjective selection of data. Premises of the scientific descriptions must specify how data qualifies. These scientific descriptions are, of course, models.

Mental development. This Strategy features the creation of a nutritive environment, a Petri dish if you will, for the brief windows of opportunity in intellectual development. While the following passages use a different taxonomy for the stages of development,

> ... the definition of "higher order thinking skills" is elusive, but we can recognize it when it occurs. It is nonalgorithmic, complex, involves multiple solutions and judgment, and it often involves uncertainty. F90-p. 195

they support the strategy of providing an enriched environment for the acquisition of skills. Support is found in the Framework in the following observations about early development:

> The Processes in the Context of Child Development.
>
> All the scientific thinking processes can be used to some extent by individuals at all ages. However, there are periods in child development in which particular processes have a higher payoff for learning, and there are periods where some processes contribute little. ... In view of these developmental stages, the parts of the scientific thinking processes are best introduced in a particular sequence F90-p. 152-3

The next table contains a summary of the Framework's discussion of developmental stages. DF89-pp. 122-3

Grades	Processes	Comments
K-3	Observing Communicating Comparing Ordering Categorizing	Young students are still building a basic mental picture of the world in which they live ...
3-6	Relating	... building upon the facts learned earlier, youngsters will derive many principles of science
6-9	Inferring Hypothesizing Designing Experiments Predicting Conceptualizing Laws of Science	They think more about the future and understand more about the past. They can comprehend concepts that are not represented by objects and materials.
9-12	Applying Decision Value Judgments	

CALIFORNIA SCIENCE FRAMEWORK
Developmental Stages
Table 1-4

Measurements. The art of measurements, so slighted in the Framework, integrates those mental processes attributed above to children in K-3. It is the direct application of the developmental traits in the table, as illustrated in this schematic:

$$\left.\begin{array}{c}\text{Communicating}\\ \text{Observing}\\ \text{Comparing}\\ \text{Categorizing}\\ \text{Ordering}\end{array}\right\} = \text{Measuring}$$

MEASURING COMPRISES DEVELOPMENT STAGES
Figure 1-7

The teacher communicates the measurement problem to the children, using precise language to specify what they are to measure. The children observe the experiment along with the measuring standards and tools available. They compare the experimental parameters to the standards. In slightly more advanced experiments, the children connect the parameters to instruments and read indicators. The children participate in categorizing the data for plotting, again communicating, this time to the person making the graph. Students participate in ordering by making and observing graphs. They also participate in ordering in putting the experiment together and in the application of measuring instruments.

The practice of measuring is a super-charged tool for developing an experimentally based intuition for the abstractions of graphics and algebra. Measurements, the objective foundation of science, become the backbone of a strategic curriculum. As the Framework says about the secondary school curriculum,

> Students [should] understand the limitations of measurements and observations and learn how to communicate clearly the true meaning and limits of investigatory activities. F90-p. 165

Measurement training flows smoothly into the essential mathematical arts:

> ... so coordination with the mathematics curriculum is essential for science and mathematics. F90-p. 195
>
> The practice of computational, measurement, and graphing skills makes obvious connections between mathematics and science. F90-p. 195

and

> ... science should be explicitly integrated with other disciplines, especially linguistic, historical, and mathematical fields. It should not be seen as an isolated discipline estranged from other fields of inquiry, such as the arts and health. F90-p. 207

Using measurements not only capitalizes on recognized skills in these early years, but it leads naturally into the essences of science. It opens the curriculum to any field of science in any proportion. It integrates the fields of mathematics and language, and reinforces necessary training in logic and randomness. Perhaps the best of all is that it is a formula for activity-based science training. It is a program that keeps children on their feet, moving toward goals, and rewarding them with insight.

Certainty. Measurement training helps students develop a perspective of how brief and limited man's observations are, and how an accuracy limitation underlies each measurement. In the end all science has a residual uncertainty. The Framework is right, although the language is a bit strong, when it says

> In science, there is no truth. F90-p. 206

but better,

> Nothing in science, or in any other field, should be taught dogmatically. F90-p. 206.

Not Evolutionism, not Environmentalism, not even Conservationism.

The knowledge of science resides in its models. The school system should skip over any quest for truth. In its place will stand the wonders of the predictive power of science. A power that enables man to know and manage his world because of his scientific models. These models, central to the Scientific Method, are not foreign to human thought processes.

Closing on its section on mental development, the Draft Framework says,

> A growing body of research on teaching demonstrates how children come to create meaning for themselves using complex representations that function as models for the natural world. DF89-p. 125

This idea was part of the theories of Swiss psychologist Jean Piaget, who was a pioneer in child development. As the Encyclopedia Britannica says in his biographical sketch,

> Piaget saw the child as constantly creating and recreating his own model of reality ... EB86-v. 9, p. 416-2b

Unfortunately and for no known reason, the final edition of the Framework removed any reference to models:

> Children create meaning for themselves; conceptualization is promoted and made more useful when presented in the context of an appropriate theoretical structure. Students construct representations of many types of knowledge, but these mental maps are especially powerful in the ways students learn (or fail to learn) science concepts. F90-p. 155

This omission eliminates the common ground between science, knowledge, and the development of the intellect. Children, but, alas, not the Framework, are on the right track! Now, give them the Scientific Method and they will have knowledge.

CHAPTER TWO
SCIENCE LITERACY

THE CASE OF THE MISSING DEFINITION

Not too long ago, a judge in Texas handed down a decision in a historic legal case for education. He had taken under consideration the pleading of a religious group against the curriculum of a local school system. It was a familiar story. The group was demanding the teaching of Creation Science as an alternative theory for the origins of life. In his decision, the story goes, the judge said that he was not convinced by the arguments of either side. His decision, he told the assembled courtroom, rested on three observations of his own making. First, he could not find Creation in science text books. Second, he didn't find Creation in science curricula, as well. And third, he could not see that Creation was a part of what scientists do. Therefore, he concluded, Creation Science was not science and the local school system need not teach it in science courses.

From the standards of this Strategy for Science Literacy, the judge's decision was correct but wholly for the wrong reasons! To understand why, consider the following imaginary situation, which a physicist would call a thought experiment:

> A bright young engineer discovers some previously overlooked patterns in economic data. He quantifies these patterns, develops the thoughts formally, and creates a new model that closely accounts for all relevant microeconomic and macroeconomic data. Moreover, he specifies rules for that relevancy ahead of time, as he should.
>
> His model yields predictions for economic parameters previously unsuspected, but which everyone soon will find easy to check. Furthermore, the model shows for the first time in the history of Economics how to implant a prosperous free market economy where none exists, as in the resurrection of the Eastern Bloc countries.

By most popular criteria as well as the criteria of this Strategy, this hypothetical economic model qualifies as science. However, it fails each criterion of the three-prong test applied by the judge in the Creation Science case!

Lawyers representing the school board were unable to discover a viable definition of modern science that the judge could use to evaluate Creation Science. Dictionaries didn't help because they deliberately include every meaning used a few times. Also, dictionaries avoid giving any authoritative definitions, trying instead to give the reader the intent of a speaker in a particular context. For words with a technical meaning, dictionaries will provide a technical definition that sacrifices strength for consensus, intermixed with definitions for, say, poetic and political usage.

Nor do available publications on science step up to the task of providing a solid, workable definition of *science*. Instead they offer dialog about "What Science Is" or "What Science Is Not." They leave for teacher and student, judge and jury, scientist and theologian alike, the lexicographer's task of understanding the meaning of *science* from its contextual application. The word *evolution* doesn't get much better treatment. This practice is simply not up to scientific standards for accuracy.

Constructing a Definition for Science

As a strategic plan for science education, *Evolution in Science* tackles the problem of constructing a formal definition of science. It develops a definition that meets the needs of practitioners. At the same time, it provides criteria for accepting or rejecting new arts like Creation Science or a macroeconomic model into the domain of science. The body of knowledge that satisfies this Strategy's definition will appear capitalized — Science.

In the process of constructing a definition, the Strategy analyses what man expects Science to do. The process begins with an examination of the limitations of human perception and knowledge. Man's need to break the bounds of individual perceptions is the same need to share knowledge and creates a requirement for objectivity. This leads to both a definition and a mission statement for Science. The Strategy will declare that Science is the objective branch of knowledge.

In addition to Knowledge and Objectivity, key words in the defining process include Creativity, Discovery, Language, Logic, Mathematics, Measurements, Models, Predictions, and Validation. All of these the Strategy neatly structures in a new formulation of the Scientific Method. The Method, then, guides the Strategy, providing a rating system for models and themes, plus a background for a unified Science curriculum.

What qualifies as Science is that which practices the Scientific Method. How far an art or a model within an art can go in satisfying the Method yields criteria for acceptance or rejection. The same criteria provide quality ratings that everyone can apply unambiguously to the state of development of an art or a scientific model. The resulting subjective model grades through four progressive and familiar stages: Conjecture, Hypothesis, Theory, and Law. To these ideas, the Strategy adds definitions for Fact and Principle, fitting them into the process.

SCIENCE FOR PUBLIC CONSUMPTION

What passes as Science for public consumption is a much different matter. Ethics and competence demand much more than the regular dose of information pollution dumped at the public bland fill. Stories appear regularly under the rubric of honorable, altruistic motives — public safety, world peace, compassion for one's fellow man, compassion for all life forms, preservation of a pristine environment. Just one of these motives alone is sufficient justification to publish or broadcast an incomplete or erroneous technical story.

At one time, members of the print media held themselves to a code of ethics. A residue of that code mandates that a reporter confirm a defamatory account. Perhaps that requirement remains not so much from the public interest but as a defensive posture against liable action. Such a cynical view derives from the lack of concern for a vulnerable public, let alone for the truth, that the media exhibits in reporting stories with scientific content. As well it likely derives from sloppy ethics and methods of inquiry taught the reporter at his university.

Universities dropped many of their Schools of Journalism since the 60s, reasonably for lack of academic content. Down the drain with the bath water went the courses on journalistic ethics and the methods for responsible and efficient reporting with nothing to replace them. Reporters and newsreaders now are products of liberal arts and communication curricula, the latter containing even less academic content. Could this phenomenon be correlated with the decline in the American newspaper? In any case, the drive to introduce ethics training in science curricula should be redirected into a push for core courses in ethics for all students.

Consider the following two anguished responses by parties injured by sloppy or sensational press articles. Both criticisms appeared in *Editor & Publisher: The Fourth Estate*, (E&P). a newspaper trade journal.

Public Risk in Food Products

E&P printed the following letter to the editor from George Watts, President, National Broiler Council, on 11/3/90 under the headline, "Defends Poultry Products":

> In your issue of July 28, 1990, your magazine published a story about a college journalism department's list of 10 allegedly "underreported" news stories from 1989. Listed in tenth place was a so-called "epidemic of salmonella poisoning" attributable to the products of the chicken industry.
>
> As the creators of the list were no doubt aware, the allegations made and figures used were lifted form an article written by a lawyer in the employ of an interest group which has consistently attacked the broiler industry and the USDA. As in the past, this writer has confused, perhaps intentionally, at least one number that is not an actual statistic for poultry but, instead, an extrapolation of figures for all food-borne bacteria on

> all raw foods. The resulting implication on which the list was based is utterly false.
>
> A recent study by the National Academy of Sciences lists food-borne bacteria and chemical residues in food as the two lowest risks the public faces in normal life. As such, there is no evidence of an "epidemic" ...

According to this letter, the hot new story about an epidemic was certainly underreported, but not in the sense implied by the college journalism department. One infers from the list that the media is not telling the public about the fact of salmonella poisoning from poultry. If the letter is correct, the item is a non-story, lacking corroboration, and others have properly left it underreported. By its phrasing, the journalism department is suggesting to the public that an epidemic exists when the fact lacks confirmation. This is unethical. Furthermore, attributing the outbreak to a particular industry, even so innocuously as including it in a list of stories, is irresponsible reporting of a technical or scientific issue. The various media sources that carried the list uncritically are equally culpable.

From a journalistic standpoint, the college journalism department failed to find the more authoritative story in composing the original list. Something more serious threatens the public according to a more authoritative source, namely whatever heads the list of risks prepared by the National Academy of Sciences (NAS). The media may have left this aspect completely unreported! Secondly, the reporter chose sensationalism over information by failing to report the NAS findings as counterpoint to the salmonella poisoning source.

From a scientific standpoint, the reporter of public hazards should not blindly accept the findings of the NAS, let alone a biased non-scientist. What a responsible, trained reporter should do is test his sources against the Scientific Method. How this might be done the Strategy reports in Chapter 6 as an application of the Scientific Method.

Tropical Oils and Passive Smoking

As the regular closing feature called Shop Talk at Thirty, E&P ran an article on 9/8/90 entitled "Is the Press Playing Favorites?" It was written by Guy L. Smith IV, VP for Corporate Affairs at Philip Morris Companies, Inc. Here are some excerpts:

> ... I do not say this just as a representative of tobacco. Philip Morris is also the nation's second-largest beer brewer and its largest food company. ...
>
> ... A few years ago, for example, there was a flap over tropical oils in food products. Food companies, including us, soon cut the "killer oils," as one major daily called them, from most products. The companies could not afford the bad publicity.
>
> The trouble is that the press accepted at face value a campaign that deserved a second look. The most visible force behind the anti-tropical oils drive was the National Heart Savers Association, which has recently been in the news charging that McDonald's hamburgers poison America.
>
> Enthusiastic journalists took remarkably long to discover that the NHSA is essentially one man with one checkbook. ...
>
> The health and environment fields have been full of this kind of science-by-press-release and double-standard journalism. A few weeks ago, the *New York Times* ran a story headlined, "Evidence Mounts Against Passive Smoking." The article was about the forthcoming EPA assessment of studies of passive smoking and lung cancer. From the article — and many others like it that followed the leaking of the assessment's conclusions — you would never have guessed that 18 of the 23 studies surveyed found no statistically significant relationship of passive smoking to lung cancer. The other five were conducted in countries where lifestyles and cultures are very different from those in the United States. Indeed, *The New Republic*'s Fred Barnes said, on the McLaughlin Group, "This new thing from EPA is not science. It is ideology."

As in the story linking salmonella poisoning to poultry products, the charge is that media twice again failed to check its sources. These were not situations in which the media was vulnerable to a liable suit. The reports only involved public safety, so it's OK to go with the sensational story. The criticisms of these technology-based stories are not science issues, but ethical aspects that science can only leave to professional journalists to manage.

What the EPA needs to do is work with the school system on a breeding program for scientists, and then turn them loose in the wild. With the right kind of science literacy, the reporter and his editor should first recognize that these stories are scientific in nature. With this elementary fact established, they should be able to apply scientific criteria to investigate the sources with the diligence due by the media by their public trust. The Strategy will show how they might do this in Chapter 6 after introducing the Scientific Method.

Combustion, Transportation, and the Economy

A nationally renowned engineer, a researcher in combustion, spoke recently to a public group at a California university. He shared his research models for competing forms of energy and for air pollution. His graphs portrayed major declines in key pollutants in the South Coast[1] air quality management zone, achieved through recent emission control regulations.

He also shared his expert opinion that the automobile is doomed in the Greater Los Angeles area. It must be replaced by a mass rail transportation system, he concluded. From specific studies on combustion, he had concluded that the cost to benefit ratio of the automobile in the economic system was

[1]A region of Southern California including most of the Los Angeles basin, known to the Indian tribes hundreds of years ago as "Valley of the Smokes" because the chronic inversion layer trapped the smoke rising from campfires and teepees. It includes Los Angeles County, Orange County, and the most heavily populated areas of San Bernardino and Riverside Counties.

excessive on some absolute scale. Moreover, he had concluded that a rail transportation system would be effective in Southern California.

He may prove correct, but his research simply did not span his conclusions. He had no transportation model. He had no data showing rail performance as it depends on job and residential concentrations. He had not considered population densities and the effect these have on mass transportation demand and efficiency. He had no economic model showing the cost of air pollution, of fuel, or of the support infrastructure for automobiles.

He had no cost model for a rail system, for ground transportation at the stations, for rights of way, or for fare subsidies. He had not accounted for the benefits to local and national economics of a mobile work force. He had given no consideration to the energy consumed and its companion pollution, which are implicit in the cost of making, building, and running the rail system.

Our researcher certainly wasn't concerned that the public might prefer automobiles to railroads. The conventional wisdom is that the public wants railroads, but the right survey might show that each interviewee is thinking that everyone else is going to be on the train and he'll have clear sailing on the highways! Models for rail transportation systems show great sensitivity to assumptions about the criteria individuals use to decide whether or not to use the system. If the public underutilizes the system, it can actually *increase* both congestion and pollution. The public needs to know what assumptions are necessary to make a rail system show a cost-effective or, today, a pollution-effective result. Then they can decide for themselves whether the idea is reasonable.

In effect, despite major gains made in recent years in the air pollution levels which the engineer did share with his audience, he gave infinite weight to assumed disease, damage, and discomfort of air pollution. This automatically outweighed any benefit of a robust economy, which might, if allowed to thrive, in the long run finance real corrective measures. A combustion model does not constitute a risk benefit analysis.

Outside earshot of the speaker, a community member of the audience listened to the remarks of some engineers in the audience. He asked the group, "Which scientists are we to believe?" Much of what passes for science in the media and even in academe, practiced by honest, reputable men, is transparent as unscientific opinion. With astounding frequency, Nobel laureates expound on subjects outside anyone's expertise.

Now no reasonable person would hold with the idea that a scientist must confine his thoughts to his first-hand research. The criterion is not that they must have done the work, but rather that the work must have been done at all! Scientists are ethically bound to tell the public which part of what they say is science, and which part is opinion; then of the science, which is fact, which is law, which is theory, which is hypothesis, and which is, alas, only conjecture. This Strategy for Science Literacy proposes such rules for good, responsible science. These rules can help everyone keep reputable scientists on course and at the same be discerning of their pronouncements.

Citizens need basic knowledge about what science is supposed to be in order that they might recognize the technical distortions so prevalent today in the popular media. Journalists need training and understanding to ask the right question as part of their public duty. They need training to report technical pronouncements accurately and completely. This is achievable. Fortunately it's much easier to be a responsible critic than it is to be a mediocre scientist. No margin remains in today's society for more gullibility, for with gullibility comes gross errors. With the background provided in this Strategy, the public will be able to hold technical claims up to the light of elementary scientific and logical standards.

WHY TEACH SCIENCE?

"Science teaches people to think," runs the popular cliché. Why? How is that true? The public is not convinced, and rank and file school teachers are not convinced. What, then, is the purpose of science education? The theme of this Strategy is that indeed science training teaches people to think, but more specifically that it trains the mind to think objectively. The principles of science are not difficult to grasp; they can even be absorbed by the older brain.

However, science is of such immense scope that it threatens to make science education unmanageable. The problem is avoidable by focusing on fundamental definitions. The Strategy must make a few assumptions to lay the ground work, and it does so by proposing a set of novel axioms. In the process, the Strategy will extract guide posts for educating the young. It will readily uncover primal pedagogical values for bold, constructive changes in the science curricula. And one of the nicest features as a Strategy for Science Education is that is not a big ticket item.

The first two values apply to communicating and thinking. These values are precision in the use of language and logic. To learn science is to learn logic, which man finds imbedded in his languages. Linguist Noam Chomsky believes that the facility for language is hardwired into our brains. Such a facility could not be for a particular tongue or syntax, but receptiveness to words with syntactical and logical structures. Researchers in Artificial Intelligence have been trying to develop machine translators of language, but have been frustrated by the complexities of syntax from language to language. This Strategy is much less ambitious, suggesting no more than common logic. Do the private languages of twins contain the same logic as the great languages of the World? Do the logical words of *and, or, not,* and *if ... then* translate cleanly from language to language? If so, language and logic have an interesting potential for theological and physiological investigations.

Acquiring science literacy means learning about measurements. And with measurements comes an appreciation of

precision,
resolution,
accuracy, and
uncertainty.

Acquiring a science education is learning to present data (measurements) in graphs, which are in themselves models. So graphics introduces the processes of

modeling,
validating,
interpolating, and
extrapolating.

Many of the properties of models reveal themselves in the graphical representation of experiments. These include notions like

linearity,
superposition,
symmetry,
mathematical operations[2],
arithmetic growth,
geometric growth, and
order[3].

Science training means learning the limits of knowledge. At the same time, learning science is acquiring the skill to deal with uncertainty.

Evolution in Science will help the teacher, school board member, text book author or editor, and curricula author critique any science framework. One of the objectives of science education is to train the student to be constructively critical, to breed a healthy degree of skepticism. This is a

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2E. g., addition, subtraction

[3]E. g., first order, second order, n^{th} order.

method the Strategy will apply self-referentially, that is, to the Strategy! It applies a newly derived Scientific Method to the very definition of science.

The Strategy's construction of science helps isolate blocks to intellectual development, and helps isolate the fundamental concepts for educators to implant in the young mind. For example, the Strategy challenges the accepted female block in mathematics. It attacks the common mental block to non-deterministic thinking, usually recognized only by the few people without it.

DEALING WITH UNCERTAINTY

Expectations of Science are sometimes too high and sometimes too low. Science can never be error-free, but in the objective world, it is the best that man has. Religions on the other hand vary widely in their claims to The Truth. Perhaps the primal cause for competition between Science and religion lies in power — authority and control over society. However, the primary technical issue involves certainty.

Science training must not compete at these levels with religion. It should not react by indoctrinating students with an imagined power of certainty. Instead, children should learn the limitations and hence the strengths of science. This leaves them room for personal reconciliation with their religions. More importantly, it teaches them not the truth of a theory but the greater lessons of objective understanding and coping with uncertainty. This kind of truth in science education and philosophy, certainty replaced with demonstrated power to predict, is irrefutable. Teaching this truth strengthens the position of science.

Pointless conflicts between Creationists and some science educators, and the clamor between activist movements and rational beings inspired this Strategy. Urgency came from the accelerating disintegration of scientific and mathematical education in the U. S. This collapse has precipitated a crisis, marked by an inexcusable scientific illiteracy among high school graduates. The phenomenon is underscored by intellectuals who publicly brag about the sorry state of their mathematical and scientific knowledge. This fashionable ignorance keeps our citizens vulnerable to blatant nonsense disguised as social conscience, wasting our energies as a nation to boot.

PHILOSOPHY

While this Strategy reflects a personal philosophy, little in it is unique taken out of context. The views of science presented here first came from a generalizing of the arts of technology and development for training and retraining scientists, engineers, and technicians in industry. A little flash of insight occurred in the process when studying the boundary between technology and science. The distinction between the two is often indeterminate and arbitrary, much as the various levels of human thought are. This idea did not develop first from abstract philosophical thought, but rather from practical applications. Some years later, it was honed by critiquing educational materials, like the Draft California Science Framework.

Pieces of the philosophy presented here lie in the major and minor works of the literature with varying degrees of emphasis. As they arise, non-standard notions in the Strategy are identifiable as *claims*. For example, the Strategy claims

> The whole body of objective knowledge is the domain of science.

Philosophical questions about science, including the Scientific Method, run deep in Western literature. They have been active topics since the 17th century. Notably, Twentieth Century philosophers have gone beyond discovery and predictiveness, seeking coherence and comprehensiveness in science. This quest has met with little success.

Philosophers have fallen behind practicing scientists in this Century. The philosophy of science actually lost ground against some of the disturbing results in mathematics and physics. Most notably Gödel's Theorem and quantum mechanics lead to what Morris Kline called a loss of certainty, a loss spiked with dilemmas.[4] Nonetheless a method of sorts and predictiveness in science have persisted and grown as common themes in the practice of science. This holds whether or not the fields of science contain truth or yield to coalescing under some unifying axiomatic structure.

Philosophy is the non-productive foundation of man's productive endeavors. Every profession needs a guiding philosophy, and especially so, practicing Science. Philosophy is also the foundation of strategies — of strategic plans! However, once the philosophical foundation is laid, working Science needs to operate unfettered by its roots. As soon as scientists agree on their destination, they need to quit arguing about goals and set off on the journey. Thus the foundation of science is paradoxical. It is laced with philosophical terms, but the philosophy itself must liberate practicing science from philosophical arguments.

Few scientists trouble themselves with the deeper meanings of time, space, matter, and energy. Many find the metaphysical aspects of these subjects no more than entertainment. Most scientific work presumes their existence, and proceeds to build on pragmatic definitions.

When a scientist examines the concepts of time, space, matter, and energy too closely, the terms become ambiguous. Physicists struggled for years with independent standards for time and space. Only recently did they give up hope, dropping the standard for the meter in favor of multiplying an assumed value for the speed of light by the standard for the second.

Science, being the objective branch of knowledge, must deal with each concept in the time-space-matter-energy continuum[5] concretely. How is this to be done? The answer is, scientifically.

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[4]See, for example, H89, K85, K80, O64, W76, Z80.

[5]Continuum has become a bit trite in science writing. Here it refers explicitly to the lack of distinction between the four parameters on

The Strategy defines away the problem axiomatically. In particular, the Strategy takes the precaution of assuming that there exists a universal clock. This is somewhat heretical. Theoretical physicists trouble themselves today with the notion that time might be highly non-linear, that it might be gravity or space dependent, and that it might even run backwards!

Negative time is a hypothesis. Certain equations in quantum mechanics show a symmetry between positive and negative time, indicating that indeed the latter might exist. Still, no one has ever observed it. Time has no known vector or forcing property. Since one of the laws of thermodynamics gives time a sense of direction, the laws of thermodynamics might not hold at some subatomic particle level.

For most scientists. the working axiom is that time is linear and unidirectional. The notion of its variation in inertial reference frames is incomplete; the twin paradox remains just that, paradoxical. The fact that physicists would challenge such pragmatic axioms as that of a universal clock is not a problem! On the contrary, it is the height of good science. Practitioners can be quite comfortable doing great science and technology while restricted to an approximate domain like Newtonian mechanics.

Philosophy of Ernst Mach

Ernst Mach (1838-1916) was one of several famous physicist-philosophers of the last century. The chart on the next page locates some of the greatest names in science including the Greeks, who don't fit very well on the same scale. Interestingly, much of our science dates from the time of Shakespeare. As shown here, Mach was a contemporary of Marx, who nearly succeeded in derailing all rational processes. Some have suggested that as a scientist Freud was a fraud, and others that Steven Hawking belongs on this list.

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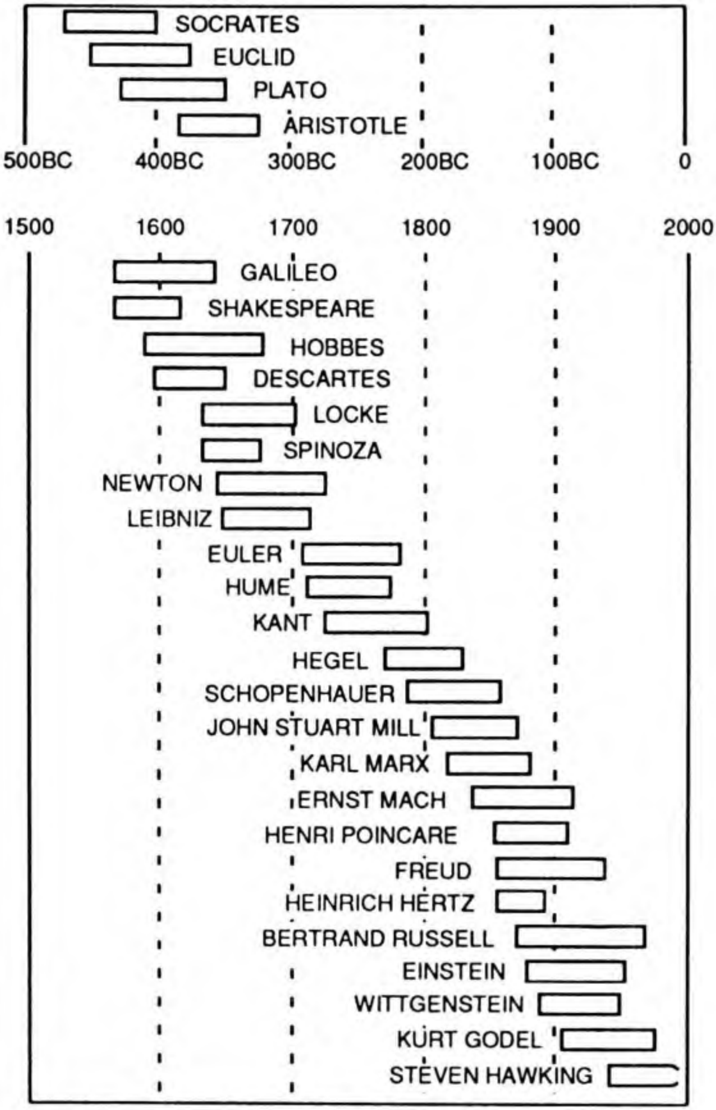
one scale or another, extending the concept for the four as if they comprised a single entity.



PHILOSOPHERS & THEIR CONTEMPORARIES

Figure 2-1

In a letter to Robert Hooke, Sir Isaac Newton wrote a line destined to become associated with his name:

> If I have seen further it is by standing upon the shoulders of Giants.

He was referring to the vision Hooke and Descartes, but his quote he borrowed from Lucan, a Greek rhetorician and poet 16 Centuries earlier. The citation was made more memorable perhaps coming from Newton, who was not noted for his humility. Regardless, the simile suggests a strong criterion for a list of greats: Whose shoulders support the pyramid of scientific thought?

Mach is singular in this group because he argued against the first model for the atom and against scientific method. He considered the atom as nothing but a mathematical model. In retrospect, he seems discredited by almost a century of physics and technology. Surely the atom exists as an entity in nature! Scientists even have remarkable photographs showing individual atomic particles embedded in the surfaces of solids.

In context with today's arguments, the Strategy can be charitable. Mach's thoughts on the atomistic view of nature should be cast in a more favorable, general context. René Descartes (1596-1650), called the father of modern philosophy, might also receive some of this charity. His strong defense of theism in his science was certainly written under duress. While Descartes was 32 years younger than the persecuted Galileo (1564-1642), they were contemporaries for almost a half Century, and look what happened to Galileo! Stupid Descartes wasn't.

Mach on Matter

In Mach's earliest days, Bohr introduced his elementary model of the atom. One can easily sympathize with anyone's intuitive aversion to this most simplistic of models. Bohr's atom is a miniature, isolated planetary system with circular orbits of hypothetical objects. The Earth was the proton at the nucleus and the Moon was the electron in orbit. Maybe

Bohr would have suggested that the electron was a thin ring of fragments if he had been a Saturnian.

Actually, Mach objected not to the simplistic but seminal model, for he held with a stronger notion of continuity in nature. Mach's argument was with quanta, indivisible particles of physical energy. Scientists have come to show, through their models, that at times both matter and energy appear quantized in nature. Certain experiments offer no alternative but to accept this duality in the models of nature.

Close to a century of experimental results since Mach's and Bohr's time has refined and strengthened the model of the atom. Is it correct? Yes, but as this Strategy claims, only so far as it has predictive value! The forces within the atom are part of a most complex scientific model. That model has successfully predicted new particles, but it remains incomplete. To the extent that the model departs from experimental results, it is an approximation.

Could someone yet prove Mach right? Perhaps matter and energy are the same thing in nature, but with a dual morphology[6]. This is not a suggestion that matter and energy are somehow equivalent because they are directly convertible from one to the other. Rather, the suggestion is that they are one and the same thing whose appearance or manifestation is state dependent, and hence experiment dependent. Perhaps an electron in orbit is actually distributed energy about a nucleus. Perhaps this merging of matter and energy in the continuum should have the name *mattergy*. It acquires particle attributes when it is no longer bound, and particle-like characteristics when stripped from its host nucleus. Could this be acceptable to Mach?

The atom was a model, a creation of man, for physicists to test against the Real World. It competed with a model of matter which was continuous. The atom model has been validated; it has been shown to have predictive value. Below the atom

[6]Meaning the same thing having multiple forms.

level are particles with state attributes of polarity and spin. Physicists hypothesize even smaller particles with fanciful names and attributes — *strangeness* and *color,* and are now suggesting even stranger sounding new parameters. These labels are nothing but given names for residual state variables, analogous in a way to the name *mass* given to the property of matter that effects inertia.

As science advances, the models become more accurate, possessing ever finer granularity and ever greater scope or scale. Which models survive depends on their utility. Often conflicting models coexist, especially so when representing matter or processes at different scales. In the end, physicists may find a universal substance or energy that comprises all matter, one that has a morphology depending upon its state and environment.

Scientific Method.

An advisory committee met recently to draft a mission statement for a budding science museum. The committee consisted of University professors, public school educators, science curators of other museums, and industrial scientists. During one of the committee meetings, an industrial member urged the group to consider illustrating the principles of the scientific method as a part of the permanent exhibit. One of the curators, a Ph. D., opposed the idea, claiming that scientific method was an obsolete concept! It was no longer in vogue, and had been somewhat discredited! That anyone might give credibility to anti-method came as a major surprise to the industrial scientist. He had been practicing and teaching a general scientific method for decades.

Method is vital in Research and Development. All too frequently engineering shortcomings are traceable to a breakdown between the industrial practices of scientific research and product development. Knowledge of the difference is critical in the execution of both. American industry invests heavily in its own basic science, only rarely receiving significant benefits from University research. While the latter often has practical goals, it generally need be only an individual scientist's search for knowledge. The measure of progress in the university is scholarly publications. By contrast, industry practices basic research over a much narrower field but with far greater intensity. Industry creates knowledge on a schedule, coordinating the work among teams representing several disciplines. Keeping industrial research coordinated, fast-paced and practical often proves to be a key to making the future transitions to development and later to production seamless and efficient. Those transitions measure of the success science in business. The kind of discipline required in industry is promoted by focusing on method. How, then, has method lost favor in some circles?

An inquiry into modern philosophical notions about method lead from the historical works of Ernst Mach, to contemporary sources like Paul Feyerabend and current articles in the Philosophy of Science Quarterly (PSQ). Judging by Mach's positions and the papers in PSQ, a legitimate argument remains enjoined. Given any choice, however, the ideas of Feyerabend, a Professor of Philosophy at the University of California, Berkeley, would receive no mention for, by his own express choice, there is no reasoning with the man! Feyerabend summarizes his anti-science, anti-Western culture beliefs neatly in the titles of his books, *Against Method* (F86) and *Farewell to Reason* (F87).

> You know, my Friends, with what a brave Carouse
> I made a Second Marriage in my house;
> Divorced old barren Reason from my Bed
> And took the Daughter of the Vine to Spouse.
> Fitzgerald as "Omar" (F52, LV, p. 162)

So Feyerabend would receive no notice here except that his proudly irrational teachings may have, as Omar Khayyam suggests, intoxicated the science curator of a major metropolitan science and technology museum! Whatever the vintage, a bit was served to a fledgling museum's science advisory committee. As a result, this Strategy for Science Literacy invites only the rational to the party, and proceeds

Perhaps the most important distinction among the various ways is the idea of logical and sequential ordering. Practitioners of system engineering and computer science routinely make a distinction between these two. When read

onward to discover and define Scientific Method in pragmatic terms.

Mach's argument against method were against a specific procedure — an ordered set of steps that true science must follow. Modern day critics, like Feyerabend, may be objecting to the method for the same reason. But where is it written that the Scientific Method must be a time sequence ordering of steps? Why shouldn't method refer to the attributes of whatever set of steps an individual or team might follow in time? The Scientific Method is like the list of ingredients in the recipe, not the steps in the preparation. The problem is first semantic, involving the meaning of the word *method*.

Exploring Method. The process of dissecting word meaning is most instructive if not dangerously pedantic. Because the Strategy rebuts authorities in claiming not only that Scientific Method exists but that it is alive and well, the meaning of the word method needs special treatment. On the next page is a summary of the synonyms of *method* taken from the American Heritage Dictionary. The table includes the essence of the dictionary definition along with some properties extracted from the definitions.

Method Definition

Semantically, it's a jungle out there. How do philosophers conduct an argument about the merits and liabilities of method without making the subtle distinctions clear?

System might fit some of the ancillary practices required in scientific endeavors. Examples include getting papers published, honoring practitioners with awards, conducting research locally within schools and universities, and conducting research and development within industry. The scope of meaning for *System* is too great.

Word	Definition	Agent	Attributes
Way	Usually an inclusive synonym for all terms.		
System	Broader scope, stresses order & regularity affecting all parts of a complex procedure.	external	ordered, regular, complex
Method	Emphasizes procedures according to a detailed, logically ordered plan.	external	detailed, logically ordered
Routine	Stresses procedure from standpoint of detail & rather rigid sequence; involves only mechanical skills necessary for unvarying practice.	external	detailed, sequential, automatic
Mode	Often applies to distinctive procedure characteristic of a group & influenced by local tradition & customs.	society	traditional, customary
Manner	Emphasizes personal behavior & distinctive procedure over logic & order.	personal	distinctive, personal
Fashion	Usually applies to individual, highly personal behavior;	personal	behavioral
after a fashion, in one's fashion, in one's way	Suggest (unfavorably) idiosyncrasies or mannerisms.	personal	behavioral

WAYS & METHODS
Table 2-1

comparatively, the American Heritage dictionary appears to make the same distinction.

In defending Scientific Method, this Strategy emphasizes logical ordering to the exclusion of a time sequential routine. Scientists might follow the Method most frequently top down, and it might be most efficient to do so, but it is not a requirement.

In no sense is *routine* necessary or invited. *Routine* is for automatons. The Strategy is sympathetic to any critics of scientific method who might have been arguing against routine. The Strategy eschews *routine* and demands *method*. *Routine* restricts mental development and blocks scientific discovery, while *method* engages and enlarges the creative mental processes.

Laudan's Criteria

The debate about the existence and meaning of method is most current. Gerald Doppelt[7](D90) commented on the position of a contemporary. Doppelt said, "Do [Larry] Laudan[8] and I have the same thing in mind when we refer to scientific methodology?" In this reference, he credits the following methodological as Laudan's criteria:

(1) Prefer simple theories to complex ones
(2) Accept a new theory only if it can explain all the successes of its predecessors
(3) Reject inconsistent theories
(4) Propound only falsifiable theories
(5) Avoid theories that postulate unobservable entities (the inductionist rule)
(6) Prefer theories that make successful surprising predictions over theories which explain only what is already known (the rule of predesignation)

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[7]Department of Philosophy, University of California, San Diego

[8]Laudan, L., *Progress or Rationality? The prospects for Normative Naturalism,* American Philosophy Quarterly, Vol. 24,, 1987; pp. 19-32

(7) Prefer theories that explain, or are confirmed by a wide variety of phenomena distinct from those which they were initially introduced in order to explain (principle of the consilience[9] of inductions[10])

He continues, discussing whether these are Laudan's "hypothetical imperatives" or his "non-instrumental methodological standards". Here are some brief titles for Laudan's attributes:

(1) Elegance
(2) Hierarchy
(3) Consistency
(4) Falsifiability
(5) Observability
(6) Predesignation (or novelty)
(7) Explanation

This Strategy proposes a single, dominant criterion for Science, namely Predictive Value.

Predicting

How to Predict a Magnitude 9 Earthquake to the Day with One Hundred Percent Accuracy:

"There will be one tomorrow."
Repeat every day.

Science must do better than chance to a prescribed error level.

The Strategy will not claim that the principal of prediction is sufficient in science. The claim is that in order for a science to be complete, prediction is necessary, not sufficient. Any science may be decomposed into a number of constituent parts, some of which would be missing prediction. A scientist can stake out a legitimate scientific career in a portion of his science, such as in making measurements and observations,

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[9]Consilience = concurrence or accordance in inferences.

[10]Consilience of inductions is the agreement of inductive results by two widely different routes.

in developing taxonomies, in developing and applying data bases, or in developing theorems. These are tangential or support roles, not primary scientific enterprises.

Similarly, the Strategy does not demand that the scientist himself make the predictions. Rather, it insists that he understand his science philosophically and universally. He must understand the models that his science develops and the degree to which they have predictive power.

The Strategy lets an individual's psyche take refuge in the ability of science to predict, satisfying any urges that it has to have nature, life, and the universe explained. This is the subjective side of prediction, the personal satisfaction gained from the scientific model and its efficiency, truth, or beauty.

The goal of science is to predict, implying that a process is under observation. Scientific models might actually predict backward in time, as when an archeologist submits a sample to carbon dating. The prediction in the usual sense is a forecast of the results of the carbon dating. Each archeologist estimates a date for his sample, even if casually, informally -- in the back of his mind. He seeks confirmation. When it occurs, his model is strengthened; its validation is reinforced. Otherwise, he must re-sort the data and create a new novel model. Then, he repeats the process.

Even though physics is butting its head against paradoxes at the macro and micro scales of matter, there isn't much of a philosophical debate in physics between prediction and explanation.

Big Bang. Was the background radiation of the Big Bang predicted, or was it just predictable? When does a model contain a prediction? That may be subject to interpretation.

Quantum Physics. Quantum equations for subatomic particles contain parameters referred to as quantum numbers. Physicists found a set of these quantum numbers that would properly account for particles that previously observed. However, the particles defined by this set included other possible configurations. The pattern extended beyond the observations. Scientists devised experiments to search specifically for the implied missing particles, and indeed they found some.

Gravity. Newton's Law of Gravity was an elegant accounting for the motion of the planets. It provided theoretical paths for the planets and other bodies observed in the solar system. In particular, astronomers applied it to Uranus, which they knew to have a peculiar orbit that might be caused by an unknown planet. Urban-Jean-Joseph LeVerrier and John Couch Adams used Newton's gravitational formula, along with a good bit of luck, to predict the position of this unknown planet. Thus they discovered Neptune with less than a 2.5^0 error. Scientists and the public viewed this as a great validation of Newton's Law. Later calculations showed that the astronomers had been lucky in the choice of the semimajor axis of the orbit, and that the error could have easily been as great as 30^0!

Corrections of the theoretical orbit of Uranus made from data on Neptune still had an excessive residual error. Several people guessed at another undiscovered planet. Percival Lowell calculated its position and set in motion the process of discovery of Pluto.

Physicists added the planetary predictions to the Law of Gravity well after Newton announced his model. Such specific predictions of the Theory of Gravity were not required to validate the model, since from the outset the theory could be checked by computations.

The controversy between Creationism and biology is the one that obliges sharpening of the definition of science. It is biology and the life sciences in general that tolerate the absence of predictions in science. At the next level of concern is economics, where non-predictability doesn't seem to embarrass any one, in spite of the application of powerful scientific tools. At this level, economics is but one of the social sciences!

The revolution in life sciences is just the beginning, leading to prediction of macro effects from molecular structure, to pinpointing DNA mutations that affect structure and function. It will never end. Biology is no longer simply observing, cataloging, and discovering. Knowledge of DNA in particular will revise if not replace classical taxonomy.

Validation.

The Scientific Method does not require such marvelous and specific predictions of a model as the discovery of a planet. In Newton's model for gravity, data were in such abundance and of such an anomalous nature that his contemporaries must have been confident that validation, or falsification if it were to come, was certain.

Similar validation occurs in modern technology. A single data history for a phenomenon can validate a relatively low order model. For example, a trace on an oscilloscope of a circuit, the telemetry of a vehicle in motion, or the image from a particle in a cloud chamber if complex enough in structure can be strong confirmation or denial of the predicting model.

An accident of validation conceivably could precede the model. That is, scientists may discover a phenomenon by testing something and build up an entirely novel model to account for the validating experiment. This is not unusual!

Laudan Criteria under the Prediction Criterion. How do the arguments in the Laudan Criteria fair under the prediction criterion?

(1) Elegance. Elegance is a highly valued quality sought in scientific theories. However predictive value transcends elegance. If a model has predictive value over contemporary models, some researcher will certainly attempt to extract the essence from the new theory to increase its elegance. In the end, though, an inelegant theory is preferable to no theory, and a novel prediction from inelegant sources is a scientific prize.

(2) Hierarchy. Scientists should come forward with any new theory of predictive value, even if it fails to account for some previously modeled phenomena. The new theory, once

validated, contributes to science and offers researchers a new view which just might be profitable. A novel prediction transcends completeness.

Of course, previous successes according to the definition proposed here are successful predictions. Once a prediction is validated, the predicted data automatically and instantly become part of the *domain* of the model. The fact of the prediction and its confirmation is history. For example, Newton's theory of gravitational attraction accounted for data that included seven known planets. His model pointed to the discovery of Neptune and Pluto, planets 8 and 9. Historically, this contributed to the validation of his model, and its subjective elevation to a Law. Now, the orbits of Neptune and Pluto are but confirming data in the domain of the Law of Gravity. As the theory gathers momentum by accumulating successes, it subsumes its predictions. Theories grow by eating their young; they feast on their own predictions. The predictions become part of a larger domain as scientists expand the theory reaching for new predictions.

Today, Einstein's General Theory of Relativity recasts Newton's Law of gravitation in remarkably new terms, not in terms of forces but as a distortion of time and space caused by mass itself. No one would sensibly ask that Einstein calibrate his new theory on the orbits of the first seven planets. Nor would anyone ask his new theory to predict the existence and location of numbers eight and nine. The new theory needn't account for the successes of the previous theory in that sense.

Suppose a scientist postulated some new model that accounted for the formation and dynamics of the various planetary rings, and that it accounted for all planetary orbits except, say, Pluto's. Further, suppose that this model successfully pointed to the discovery of some previously unknown asteroids. This new theory would be accepted provisionally, and that would be consistent with the Scientific Method.

(3) Consistency. Could any theory which is qualitatively inconsistent with itself predict with usefully low errors? Possibly, and it may therefore be the best theory available. Of

course, science demands that to have value, a prediction must be better than chance and produce reasonably small errors. That is, the prediction must have some worldly or theoretical use. In the terms of a communication scientist, it must contain information.

(4) Falsifiability. Karl Raimund Popper formulated the Principle of Falsification to help exclude pursuits like the pseudo-sciences and theories like Marxist history from science. A scientist, Popper claimed, should propose an experiment that could falsify his model. When that experiment fails to disprove his theory, he has an incidence of confirmation. Conversely, when the experiment falsifies the model, the model is rejected. The scientist counters this unfortunate result easily by repairing the model. He excludes the experiment by changing the rules that specify the model's domain.

Suppose an astronomer developed a model for the atmospheric circulations of the planets. Suppose further that it successfully predicted the changing shape and rotation rate of the Great Red Spot on Jupiter. This would be a major scientific achievement! Now suppose the same astronomer is a Popperist, subscribing to the Principle of Falsification. He proposes a test on earthly cyclones that could falsify his theory. His colleagues collect the data, and the experiment shows indeed that his theory does not hold!

Is the greatness of his prediction about the Red Spot lessened? Should he have never propounded his theory? No. What he does is something as simple as redefine the model to apply only to the gaseous outer planets. QED.

A scientist can narrow the domain of his theory arbitrarily, almost to the vanishing point. The hypothetical model for atmospheric circulation is a major achievement if it applies only to Jupiter, or only to the Great Red Spot of Jupiter.

Scientific method must insist that theories be capable of validation through prediction, and that the theory itself be based on some non-empty data set. In fact, this may be the intent of Popper's falsification. The model must be a representation of measured objects or measured phenomena. The scientific method has no room for a table of sizes and rotation rates for the Great Red Spot only in the future, whether or not the table proves correct.

In short, falsifiability applies to a model's predictive value.

(5) Observability. The scientific method requires that models account for observables and predict observables. There is no room for unobservable entities, even as catalysts to the model's processes. An idea like the ether for the medium of light waves should today receive no credence beyond a conjecture unless the model maker can postulate an immediate falsifying experiment. There is also no room for phantom relationships or the supernatural.

The unscrupulous scientist can adjust almost any model to produce a preconceived conclusion. For example, if atmospheric warming is the desired result of carbon dioxide (CO_2) emissions, a technician can adjust any model to make that happen. Someday a validated model might exist for global climate, but the model in this hypothetical discussion might not use CO_2 as a parameter at all! The unscrupulous scientist could insert the CO_2 parameter simply to make the predicted global temperature follow the CO_2 concentration. This is a phantom relationship.

Subjective results from models need not be so overt and deliberately misleading. A research team simply adds CO_2 effects, adjusting the model's parameters until they attain a reasonable, anticipated effect. In the process, though, bias creeps in unknowingly and objectivity is lost. This is self-delusion until they make the results public, whereupon it becomes at least irresponsible.

For both ethical and pragmatic purposes, scientific practices dictate that any model rest upon the full set of measurements within its domain. Still, scientists retain a great deal of power over the modeling process. They do so by exercising their option to define the domain of observations. Any scientist may redefine the domain of his model at any time, but he must always provide an unambiguous set of rules which qualify data for the domain. A research team can configure its own model as it wishes, determining how parameters are significant. They configure how the parameters affect the model results, adjusting coefficients and values within the model to produce quantitative output.

Here is a more blatant hypothetical case. Imagine an atmospheric scientist working with a state-of-the-art Global Climate Model (GCM), that is, one which as yet can predict neither climate nor weather! He is asked, "What are the effects of chlorofluorocarbons going to be on the public? " So he proceeds semi-scientifically as follows. First, he inserts

a model for ozone (O_3) creation into his GCM,

where before O_3 was simply a constant layer with fixed thickness and concentration. Then he adds a model for

CFC concentrations at low altitudes,
CFC transport to the high altitude ozone layer,
CFC dissociation into chlorine ions,
UV transmission through the atmosphere,
each for the incidence of cancer, cataracts, and
agricultural effects caused by UV light, and
starvation from the agricultural effects.

He fixes his ozone creation model so that it shows the expected thinning caused by the chlorine ions. Then he undertakes the monumental task of adjusting all the parameters of this complex, open loop GCM/CFC/O_3/UV model, augmented with epidemiological, agricultural, and economic effects, just to get it to run on his supercomputer. As soon as the results produce sufficiently alarming but believable results, he calls a press conference. Such unscrupulous conduct is pure conjecture, but it is a possible scenario based on all reports in the media!

In many complex models, scientists can exploit this modeling process to produce nearly any result. Therefore, ethics demands a measure of validation of the model before anyone uses it for public policy. The model must predict some qualitatively new result which the scientist has shared publicly. This gives other scientists, professional or amateur, but with differing set of biases, the opportunity to confirm the model through repeated, consistent measurements. Once the model has earned its a measure of validation, it is suitable for public policy. A private model is not Science.

Continuing the first example above, a global climate model must first fit past data. When the creators of the model publish their result, the scientific community will study the new theory. Since they know that the world is waiting for a way to predict the effects of CO_2 concentration on global temperatures, they will look specifically to see how the creators of the model mechanized that relationship. To satisfy its desired purposes, the model must use CO_2 concentrations as dictated by historical data. The relationship between CO_2 concentration and average global temperatures must be representative of relevant data. The concentration of CO_2 must take part in the reaction of the model as it reproduces facts.

The model must then predict some qualitatively new phenomena, perhaps continental weather patterns for a year or measured variations in gas mixtures by latitude and season. Once the scientific community confirms the predictions with measurements, scientists can approve the model to predict the effects of CO_2 increases.

(6) Predesignation. The notion of surprising results is not essential, for it is a subjective concept. Even the absolute requirement for predictions is broad because the model is free to proclaim its own accuracy. This Strategy proposes a subjective quality for the model called *utility*. The prediction should have some value.

(7) Explanation. Explanation has several interpretations. In the weak sense, Science explains by accounting for some facts of the Real World. Models construct a link between Cause and Effect. In the strong sense, "to explain" is subjective, satisfying the listener somehow. In this latter

sense, it is external to Science. Explanation is in the eye of the beholder, but the power in science and its explanatory strength is in its ability to predict.

Philosophy.

Ah, the delights of philosophical pursuits. Beware its slippery slopes; it is a vortex that will draw you into an intellectual black hole. By dint of argument, soon nothing will exist, or be known, or be knowable. You might not ever escape!

Mach might agree with the proposals and philosophy of this Strategy. Mach though may have been the first to say that the objective of science is to describe. That view led to another, earlier round of great philosophical debates. What is unfamiliar needs exploration and discovery. These debates can engage philosophers, though a different tack might be more productive.

Philosophy suffers from the same disease as Artificial Intelligence (AI) — experimenters can resolve nothing and remain in the field. For whatever becomes known becomes science and whatever becomes do-able by a machine is no longer AI. The same problem applies to the supernatural and measurements, for once something yields to measurements it is no longer supernatural. Scientists cannot argue the merits of anything without a working definition, one that leads to a test at least of existence.

Some researchers might have trouble with the requirement of prediction, such as those working in neural networks or perhaps devoting a lifetime to botanical field work. Neural networks today is a branch of AI, the undefined science. Practitioners have microscopic but no macroscopic models for these networks. They have no algorithms for their learning, in fact they like to say that it is non-algorithmic. As industry wags say, "If you can't fix it, feature it." In the long run, neural nets need to have a predictable output or transfer function, converging reliably as they learn.

Perhaps AI requires that a machine acquire self-awareness, a conscience, or ethics. Until researchers define AI clearly in advance, the art is doomed as someone said to "truly remarkable programming" within Science. Perhaps Science then is Real Intelligence (RI).

Because a field of science doesn't know the complete answer, it does not disqualify as a science. Thermodynamics contains statistical models. Until AI contains models even statistically shown to be practical, it just remains in the basic research phase.

Philosophy is seductive. It is a trap, like the games of bridge or chess to a student, or like studies to one susceptible to the disease of the professional student. Beware Philophilosophia.

STRATEGIC PLANNING

Strategic Documents

Well-prepared guiding documents like strategic plans and frameworks become working documents in practice. Initially, each is a nucleus for incremental improvements over the years. In this light, the current plan in California to update frameworks cyclically is most unfortunate. It means that the community revisits the Science Framework only once every seven years or so. Instead, each Frameworks should be a loose leaf document, a 20 year plan updated every six months, or better updated asynchronously, meaning as new concepts develop.

A strategic plan is a concise foundation for an undertaking. It includes slowly changing concepts like philosophies and definitions, and so will have the longest planning horizon. For science education, that horizon might be as distant as a Century.

Strategic plans define the intent of an undertaking at various levels. A raft of synonyms for *intent*[11] are available in English, but in the art of strategic planning three are nearly standard: *mission, goals*, and *objectives*. A mission has come

[11]In addition to *mission, goals*, and *objectives* are *intent, intention, aim, end, purpose*, and *object*.

to mean the enduring responsibility assigned to an undertaking. It reflects the charter given to the practitioners by the authority to whom they report, defining who is master and who is slave. Often in practice the mission statements serve to distinguish one undertaking from another.

Goals are ideal accomplishments set for the undertaking within the bounds of the mission statement. They are generally unmeasurable, and hence subjective. They often are enduring, lacking a specific time of completion. They may contain subjective aspects of quality and ethics.

Objectives are demonstrable ends leading to the goals set for the undertaking. They include both measurable accomplishments that have a specific period of performance, and demonstrable methods put in practice on a continuing basis. Objectives invite measures of success for the undertaking.

Once a working definition of science is available, the Strategy will propose a set of mission, goals, and objectives statements for both Science and science education. These are the subjects of Chapter 4.

A framework is a collection of guidelines for individual educational fields. It is the first stage following a strategic plan for education, and would elaborate upon the objectives for each discipline. It contains an overview of principles required of texts, curricula, and lesson plans. The framework, as suggested above, might plan for the next two decades. Ideally, it would set short term objectives, a plan of action including people and resources, and a schedule.

Precision in Language

Being cornerstone endeavors, strategic plans are brief and economical in the use of words. The words have a disproportionate effect not only because the plans use few of them, but because subsequent actions amplify them as the plans are effected. That leverage through the system engineers call gain. Having so much gain in strategic plans means that the scientific prerequisite for precision in language is especially acute. Before educators can craft complete science frameworks and curricula, they need a crisp, clear, complete definition of science. Educators need an operative definition of the role of mathematics and its relevance to the students who will continue in science as well as to the much larger group who will never pursue technical careers.

A strategy for instruction in science must satisfy teachers and parents who are neither scientists nor mathematicians themselves, but find that they must guide students in both fields. A principal theme of this work is to give educators material that they can share with children as mathematical and scientific experiences presented during their most formative years. The Strategy applies this idea quite literally. It defers the teaching of formal theories and jargons of science until after the child has a working familiarity with both the concepts and the words. Nonetheless, teachers should answer precocious questions to the best of their ability when they arise.

The Strategy will from time to time, or place to place, refer to scientific or philosophic concepts in polysyllabic words. These words are used because they are descriptive. Do not read into their use here that the Strategy advocates exposing young children to words like *etymology*, *epistemology*, *thermodynamics*, or even *probability*. Indeed, the strategy is that the curriculum will familiarize students with the principles of etymology, epistemology, thermodynamics, and probability by example. The intent is to make the notions comfortable to students in their thoughts before holding them accountable for the names of the processes. This makes advanced notions like these much less abstract.

The curriculum should teach children the decomposition of words into phonemes[12] and root forms long before it exposes to them that they are receiving *phonics* and *etymology* (etumos, true; true meaning, atomic value of a word). The Strategy advocates six to nine years of experience before the word *etymological* first appears on a vocabulary test.

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[12]Atoms of speech, elementary utterances.

Role of Philosophy

Teaching philosophy is not a goal of science education. Philosophical pursuits are recreation for the practicing scientist, but science in practice has little concern with such ideas. One of the objectives of a strategy is to establish the underlying philosophy of a human pursuit so that the activity can proceed without continuously engaging deeper questions. This Strategy for Science Literacy proposes do just that with regard to both Science and science education. The result is that any philosophical arguments are matters for the Strategy and hence have the least possible effect on either the frameworks or the curricula.

Science is Secular

Segregating philosophy, the classroom like the laboratory can stand clear of religion and its dogmas. Science, not necessarily scientists, must be secular. If science seeks to predict, not explain, it can with some safety duck the Creationist's claim of foul. Like all scientific endeavors, the predictions won't be certain, but just probable.

Some zealots will insist on teaching Creationism or environmentalism as science, and others may insist on burning science books. Educators can only give their best effort, showing little tolerance for such intolerance. While they are wearing their science hats they can leave the questions of God or beauty in the world to the individual conscience and to the prerogatives of parents. Science can be neither theological nor atheistic, until someone can develop a model with theological hypotheses, use it to predict, and validate the results. Science is secular, and needs a secular definition.

Claiming that Science is secular, and broadening the meaning of secular to include all beliefs, in no way means to imply that the practice of science proceeds absent ethics and public responsibilities. Science has discarded the supernatural, becoming secular in practice. Secular here means not only separate from religion, but distinct from all belief systems, including science's own methodologies. Hence, it is anti-self-referential. The dictionary defines secular as distinct from eternity also, so someday science may be independent of the concept of infinity (and its reciprocal, infinitesimal). Then it will be free from induction. Someday it may be free from induction, infinity, self-referencing, spiritual, and subjective notions. In this ultimate state, man will still find in this objective world an ample supply of truth and beauty. This Strategy denies to Science the ability to self-reference with subjective notions.

Goal of Critical Thinking

The goal of science education is to teach and prepare students for critical thinking first, and for science second. The Strategy cannot argue for a K-12 curriculum geared to college science majors. Too few students fit this category, and the U. S. public at large is no longer ready for this step. In Japan, a child feels devastated when the state decides that he will not pursue the science curriculum. American children are mortified if anyone should think that they have any interest in science or mathematics after grade 6.

Surveys of American children in K-3 place science, including technology and mathematics, first or second as career interests. By sixth grade, science ranks dead last! The United States school system manages to beat any interest in science out of the students by the time they have finished elementary school! Teachers at each grade level report the same problems — entering students are ill-prepared and under-motivated. High school teachers accuse intermediate schools; intermediate school teachers blame grammar schools; and even 6th grade teachers blame the system in K-3. The consensus is clear, the system does it to our children. The loss to the nation is costly and unnecessary.

Our children come to believe that Science is an exotic, isolated activity for grown-up nerds. The new breed of political activists characterize science and technology as threats to our lives and our environment. This is a tragic consequence of scientific illiteracy on the parts of both the speaker and the messenger. It is an indictment of our national school system and our media. The truth of these views is demonstrable, for much of what passes today as education in the U. S. is indoctrination.

Meanwhile, other studies predict a severe national shortage of scientists, including mathematicians and engineers, within the next 15 years. In the recessionary climate of the early 90s, lead by a mothballing of the defense industry, this shortage is less likely to materialize. In any case, the nation will manage to survive the loss. Industry and academe will attract scientists from overseas, and manage by bringing more of the highly skilled individuals out of retirement if need be. Moreover, the economic system will make these careers more attractive should the need materialize. Free market economies are nothing if not self-righting.

The tragedy is not the loss of highly trained individuals. The larger casualty is the ever growing science illiteracy in the public at large. Americans are vulnerable to charlatans, fakers, emotionalism, populist causes, and demagogues. The educational system today promotes a growing loss of healthy skepticism. It denies our citizens their capacities to make independent judgments and to be independent human beings. These are birth rights in the U. S.

Western Values at Risk

The nation exhibits a growing inability to think rationally, to be analytical. Our citizens are losing their native ability to challenge those who would turn heads for personal gain and power, or in pursuit of some ill-conceived social program. Our citizens learn to react as groups rather than as free individuals, because this is most economical for those who would manipulate and exploit them. This drains our national will and power.

The United States, as the leader of the Western World, has been at the forefront of every movement valued by Western man. Critics of the U. S. at home and abroad like to say, "What about your

slavery and treatment of the Blacks?"

treatment of the American Indians?"
incursions into Viet Nam and Korea?"
poverty, homeless, lack of medical care for the poor?"
industrial pollution, whaling, destruction of dolphins, oil spills, automobile exhaust, et cetera, et cetera?"

In every instance, the West, with the United States at the forefront, has been in the lead in correcting the universal problems of civilization. The values that produce these criticisms, and the international change to greater freedom and increased standard of living, are Western ideas. Since the Bill of Rights, the United States despite all its bumbling has been the model for change, humanitarianism, freedom, and well-being. No nation has fought harder to abolish slavery and to rid the world of tyranny, from Nazi Germany to Communist Soviet Union.

Economic Strength Protects the Environment

No system has proved stronger than one in which each citizen is free to pursue his personal dreams. No economic system has produced greater wealth for its citizens at every social level than that produced by the personal freedoms guaranteed in the United States. Our economic wealth enabled us to defeat the Nazis, and recover from the debt. It enabled us to check Soviet aggression around the globe until the Communist system buried itself under the avalanche from its own economic slag heap. No nation pollutes less than the U. S., CO_2 emissions notwithstanding. No nation spends more of its national wealth on protecting the environment and life forms. No nation has more strength or will to rectify past actions seen as mistakes only in hindsight.

Public ignorance threatens these strengths. Futile, counter-productive pursuits drain our economic strength. The nation will have a cleaner environment, but that takes money and time. The U. S. cannot afford immaculate air at the price of its economic viability. It cannot succeed in the long run by closing down businesses and chasing others across borders to pollute with impunity. It cannot simultaneously shut down the housing industry and house the homeless. The nation cannot return to a simpler, more primitive time, burning wood and doing without. Our citizens need to think clearly in terms of alternatives, not absolutes.

This last statement is a

> Scientific Principle: Make decisions based on consideration of alternatives. Never make judgments based solely on absolutes.

Technology is here to stay. And only technology promises to cure the World's ills, including those brought on by technology itself. A science literate public will not be fooled into thinking that man can burn wood for energy. They will not be confused by the poppycock masquerading as science in

* racial statistics that "prove" discrimination,
* energy use per capita data that "prove" irresponsibility or waste,
* non-uniform distribution of wealth that "proves" exploitation,
* unvalidated Cold Fusion experiments
* global warming models with no predictive power
* conjectures about ozone depletion
* arguments which begin, "What if we save one life, one deformed baby ...
* conservation and recycling long term solutions to pollution, energy,
* stopping growth to solve water, transportation, & energy problems

Our schools have the charter to develop the brain, not program it with collectivist ideas and political causes. Even if one subscribes to the idea that our ills today are consequences of societal problems, the solutions for the individual lie in promoting self-worth, self-reliance, and self-control. This is the Great Western idea of the free intellect. The United States and thereby the West have flourished because of this kind of individualism.

Remember the old gag line, "If his head had a zipper on it, he'd take his brain out and play with it!"? The brain is there not to be chemically induced into fantasies and orgasms, but to control one's own behavior. Charlatans like the once charming Guru of drugs, Timothy Leary, and the media that uncritically and unethically amplified his voice to the nation, need countering with the right kind of education.

Propagandizing our children to chant, "Just Say No!" can be no more than a palliative. The instant gratification of chemicals and of group identity combine to produce drug dependence, crime, and intolerance. Education can replace it with an enduring satisfaction that comes from understanding the world and our place in it. The goal of the system must be to teach children to think critically, armed with a few facts. This is more than the power to think objectively — it is the ability to share in the immense body of objective knowledge known as science. It is distinct from the subjective pleasures of beauty, art, and nature.

At one extreme of science education, schools need to stop spreading the idea in our young that science is a distant pursuit. That it is remote in space and incomprehensible except to a few. It is not an industry — an industry comprising white coats, eggheads, and smelly laboratories. At the other extreme, the system must emphasize that science is not the happy love of animals, the environment, or the fragile blue sphere, nor is it the Gee-Whiz wonders of discovery in nature! Just as Science is not white coats in smelly laboratories, it is not flannel shirts and hiking boots in virgin forests.

Science is a way of thinking. It is certainly not the only way, and it doesn't replace other concepts of beauty and reverence. But it is a highly rewarding way, both personally and societally. It is the practical way to solve problems.

The argument that every citizen can benefit from scientific and mathematical literacy is sufficient. Public issues today deal with interrelated, complex technical matters, such as

communications health

defense	housing
drugs	information
economics	jobs
education	pollution
energy	transportation
environment	water

The high school graduate should be literate enough in science to resist the demagogues who would prey on him. He should be technically literate enough to vote on issues and for candidates that are not parts of the problems.

While economists have yet to elevate their art to a science, it is on the verge. Economics has scientific content that every citizen should know, and every public issue must face. Unfortunately, long traditions have so enmeshed the art with politics and public policy that at times the field is unable to advance as an objective pursuit. The approach to science propounded in this Strategy will help economics break free from the grip of the pseudo-science of political economists and social science.

As a plan for education, the Strategy is to give children practical foundations for scientific theories during their most formative stages of development. In scientific jargon, this could be called à posteriori foundations for à priori knowledge. (À priori means from reasoning, or theoretical; à posteriori means from experience, or empirical.) The rule is experience before theory. The scientific and mathematical world should be a part of every child's environment from Kindergarten on, enriching him as a parent would an infant with challenging objects.

An excellent example comes from probability theory. An ideal coin has two outcomes, heads and tails, each with probability equal to one half. This model comes from pure reasoning, and so is à priori.

A real coin is likely to be slightly different, favoring, say, heads over tails, and having a small chance of landing on edge, or rolling out of the room, down the stairs, into the street, and down the drain. (Thanks to the Pink Tiger!) A gaggle of students might run a test of a million tosses with the real coin, finding that it stood on edge once, rolled away once, and 500,891 times it came out heads and 1000000 - 500,891 - 2 = 499,107 tails. From these data, they calculate the relative frequencies of heads as 0.5009 and tails as 0.4991. This is an à posterior model, and they can ask all sorts of interesting and intelligent questions about it:

> Is the coin biased?
> Are the differences between à priori and à posteriori data due to chance in the experiment?
> How often would an experiment this large be so close, or so far from the à priori predictions?
> Can students gain any more information from the data, as in looking at run lengths?

As advanced as these questions are, the preparation for answering them can begin in K-1:

> Let children run a coin tossing experiment in groups, and count up the results. The teacher can graph the results for each group and collectively as the experiment progresses. The graphs can display the individual experiments and their composite. The graphs can indicate the à priori levels of 1/2, reserving the explanation for higher grades.
>
> Students can make charts of run lengths, both in density and distribution. The charts can remain on the walls for some time for the children to absorb and ponder. Connections to theory come later — much later.

Teachers can present charting without any formal explanation for many familiar processes. As football players get little tokens for their helmets, and as students used to get little gold stars, give children "attaboys" as rewards. The trick is to make the gold stars into a cumulative graph at the earliest opportunity. Children will accept it as a part of the scholastic environment, and when the time comes to learn about the

Cartesian coordinate system, about graphs and analytic geometry, they will have a mental foundation to complete the connection with the familiar.

A STRATEGY FOR SCIENCE EDUCATION

The next chapter sets the goals of science to answer the question of why man has or needs science. This helps the Strategy formulate a fresh definition of science in Chapter 4 as the objective branch of man's knowledge. At the close of Chapter 4 are the mission, goals, and objectives of Science. An introduction to objectivity and objectivity training is the core of Chapter 5. Objectivity leads to the Scientific Method, summarized in Chapter 6 and presented with a discussion of preparation and training.

Whether science achieves its goals is the subject of Chapter 7. Before concluding the work, the Strategy adds technology as a branch of science and outlines how an educator, a juror, or a journalist can judge technology maturity. The Summary and Conclusions, Chapter 9, wraps up the main message of the Strategy for Science Education.

The epilog, Chapter 10, presents a system engineering model for evolution, cast according to the principles and method established in this Strategy. This model uses the minimum number of assumptions, two facts and one novel principle, to account for much of what biology textbooks present as macroevolution. Some of the results may be surprising.

The Strategy provides enduring elements of scientific training for K-12, using contemporary topics as examples. The Strategy promotes a unified curriculum, but the Strategy is not a curriculum. It sets down initial conditions so the process of designing the complete curriculum, starting with a new Framework, can begin.

Project 2061, Science for All Americans

The American Association for the Advancement of Science is conducting Project 2061, as it says,

> to help bring about the reform of education in science, mathematics, and technology.

Their goal is scientific literacy. The first phase consisting of six study groups, five were specific to scientific disciplines. The sixth, called Science for All Americans, addressed the general problem of science education. In their final report on the sixth phase, they organized their recommendations as depicted in the chart on the next page. The Association's taxonomy includes the following organization for Life Sciences and Socio-Political Sciences:

Life Sciences	Socio-Political Sciences
The Biosphere	Anthropology
Evolution	Sociology
Homo Sapiens	Political Science &
Physiology	Economics
Health	
Medical Technologies	

In the coming chapters, this Strategy for Science Education will answer all but one or two of these criteria.

Project 2061, Science for All Americans, published recently by the American Association for the Advance of Science, calls for "daring and experimentation" in reforming science education in the U. S. This Strategy is both. It is daring as the work of one person and not a committee. It dares to propose changes to fundamental concepts in education and to certain models and definitions in science disciplines themselves.

Project 2061 uses the word science in two ways, as demonstrated by its repeated emphasis that science literacy covers science, mathematics, and technology. This Strategy, too, uses science in two senses. The field of science includes basic science, which deals with the natural world, and technology, defined as the branch of science applied to the manmade world. When speaking of science, the context will resolve any ambiguity.

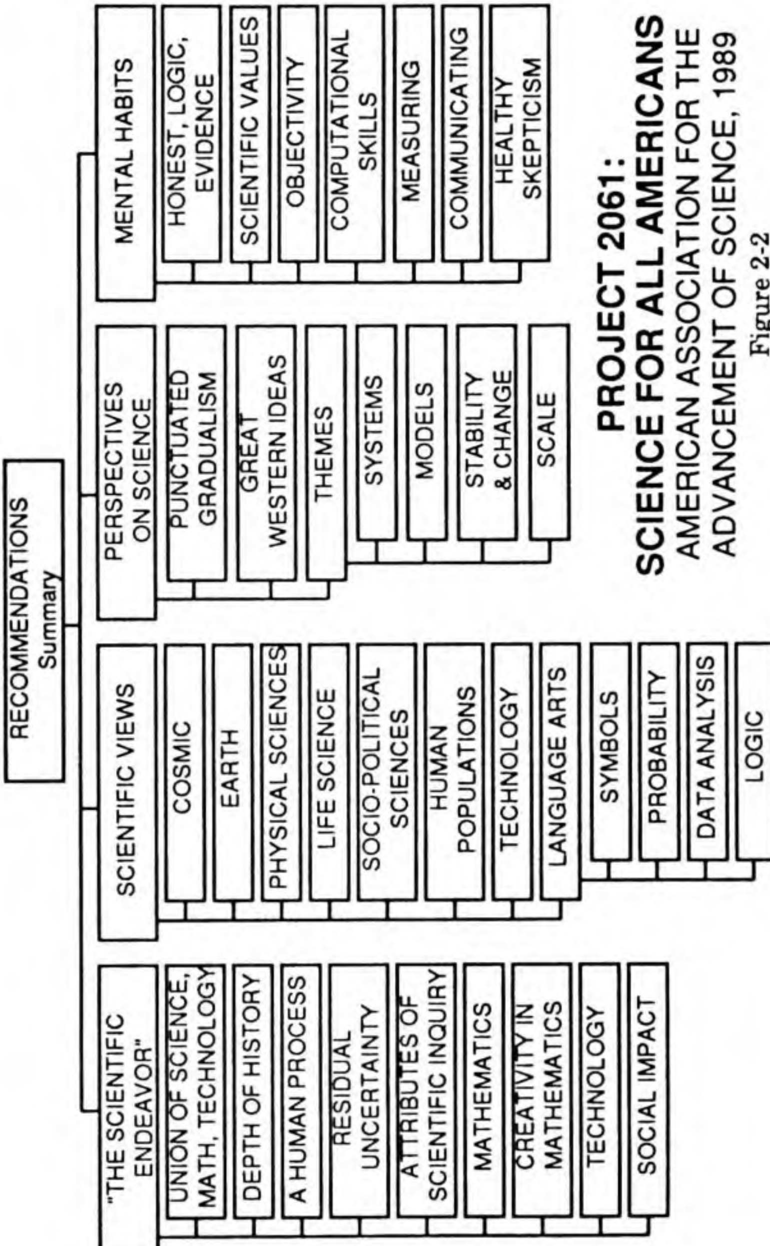
RECOMMENDATIONS
Summary
"THE SCIENTIFIC ENDEAVOR"
UNION OF SCIENCE, MATH, TECHNOLOGY
DEPTH OF HISTORY
A HUMAN PROCESS
RESIDUAL UNCERTAINTY
ATTRIBUTES OF SCIENTIFIC INQUIRY
MATHEMATICS
CREATIVITY IN MATHEMATICS
TECHNOLOGY
SOCIAL IMPACT
SCIENTIFIC VIEWS
COSMIC
EARTH
PHYSICAL SCIENCES
LIFE SCIENCE
SOCIO-POLITICAL SCIENCES
HUMAN POPULATIONS
TECHNOLOGY
LANGUAGE ARTS
SYMBOLS
PROBABILITY
DATA ANALYSIS
LOGIC
PERSPECTIVES ON SCIENCE
PUNCTUATED GRADUALISM
GREAT WESTERN IDEAS
THEMES
SYSTEMS
MODELS
STABILITY & CHANGE
SCALE
MENTAL HABITS
HONEST, LOGIC, EVIDENCE
SCIENTIFIC VALUES
OBJECTIVITY
COMPUTATIONAL SKILLS
MEASURING
COMMUNICATING
HEALTHY SKEPTICISM
PROJECT 2061:
SCIENCE FOR ALL AMERICANS
AMERICAN ASSOCIATION FOR THE
ADVANCEMENT OF SCIENCE, 1989

Figure 2-2

A Unique Strategy

Evolution in Science presents a unique strategy among the body of works published on the subject of literacy or education. As the work of a university-trained industrial scientist, it draws from two distinctly different pursuits of science.

COMPARATIVE VALUES

Industry	Academe
economic returns	theoretical advancement
speed	thoroughness
teamwork	individual achievement
secrecy	publication

As the work of a leader and trainer of industrial science and technology, it addresses pragmatic problems with the product of our educational system. As the work of a private citizen, it risks breadth for freedom from bureaucratic and traditional compromises. As the work of an individual, it is free to create. As the work of a private citizen, it is free from politically correct thinking and those destructive, politically motivated programs that substitute birthrights for the Western ideals of individual effort and achievement.

CHAPTER THREE
MAN'S ISOLATION FROM THE REAL WORLD

WHY DOES MAN NEED OR WANT SCIENCE?

Man perceives, he tries to understand and to predict. He is driven! Each of us, science trained or not, goes through a process of sensing, perceiving, abstracting, generalizing, and idealizing. The senses inherited by our species limit each individual's ultimate ability to sense, and then his experiences distort the perceptions he forms from his sensory data.

Every one of our senses has relatively tight bounds in many dimensions[1]. Much of the energy containing information about the Real World is undetectable to our senses, and other energy and matter of which we are not conscious at all somehow influences our perceptions. Physicists estimate that only 10% of the matter in the Universe radiates any electromagnetic energy at all.

Science deals with parameters, such as magnetism and many forms of radiation, that we cannot perceive. We have no direct indication of nuclear radiation, ultraviolet light, or microwave radiation, like that used in radio, television, and radar. We feel infrared radiation as heat, but we are unable to image with it.

Our senses give us no clue about the quantum nature of matter and energy. Nor do we receive any hint about either the quantum or wave nature of electromagnetic energy. Pseudo-sciences postulate extrasensory perception (ESP) in forms like mind reading and psychic knowledge. They add forces with names like telekinetics and levitation. Every

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[1]All animals, humans included, sense an n-dimensional projection of N-dimensions, where $n \ll N$. Moreover, every dimension of the n is narrowband compared to the energy available. Narrowband means that energy is lost above and below our senses in frequency or, equivalently, wavelength. This idea is imbedded in the adjective visible in visible spectrum. It implies an invisible part of the spectrum, which children can be taught lies beyond red on one side and beyond violet on the other.

student needs to learn about these sense parameters from a scientific standpoint.

Anyone comfortable in his day-to-day experiences, accepts without question that he is perceiving the Real World around him correctly. He is probably by definition a normal person. Who would doubt the quality of his perceptions when his car won't start, making him late for work on the most important day of the year? In the dark of night, when we trip over our child's rocking horse, reality can be painfully clear. Natural phenomena like lightning and thunder, and natural disasters like floods and earthquakes make reality all too apparent.

What do we think, though, of the physicist who says that a neutrino can pass right through our house, our body, our child's rocking horse, and on through the earth? We have no sense of this phenomenon. Our bodies give us no indication at all of such an event. With confidence, the Strategy speculates that most people would be thoroughly skeptical when told of such possibilities the first time. People held identical doubts about X-rays passing through solid objects! Having tripped over the toys, we might swear that the room was pitch black. Still, why doesn't our cat have these collisions? How do engineers see in the dark with infrared sensitive and low light level cameras? These are examples of data below our sensitivity thresholds.

Even objects and events that we should be able to sense perfectly pose problems. We witness a traffic accident, and give our report to the police. Three weeks later an investigator calls on us. We find that we need a reminder or two about what we saw. Two years later when cross examined in court, we find that we have become embarrassingly fuzzy about some of the facts. We grow more and more uncertain about facts as time goes on. When does forgetting start? Is this just fading memory, or were we mistaken in the first place? When do we begin to make mistakes about what we witnessed? The answer is at the outset — from the moment that it happened.

We have evidence that this is true. Well-meaning, unbiased witnesses who saw the same accident will give conflicting testimony to police at the scene. These are not simply disagreements about subjective estimates like rates of speed. They include differences of opinion about whether or not specific events occurred and in what order they happened. Which car entered the intersection first? Which way was that driver looking? Who was driving? Who had the green light? Even, which car was traveling in which direction?

PERCEPTION

Dr. David Viscott in "The Making of a Psychiatrist" says,

> Each of us perceives the world he must perceive. We invent our illusions to separate the world outside from the world within, thereby to avoid hurt and to feel comfortable. Even though the outside world is the same and feels are universal, no two people share the same illusion.

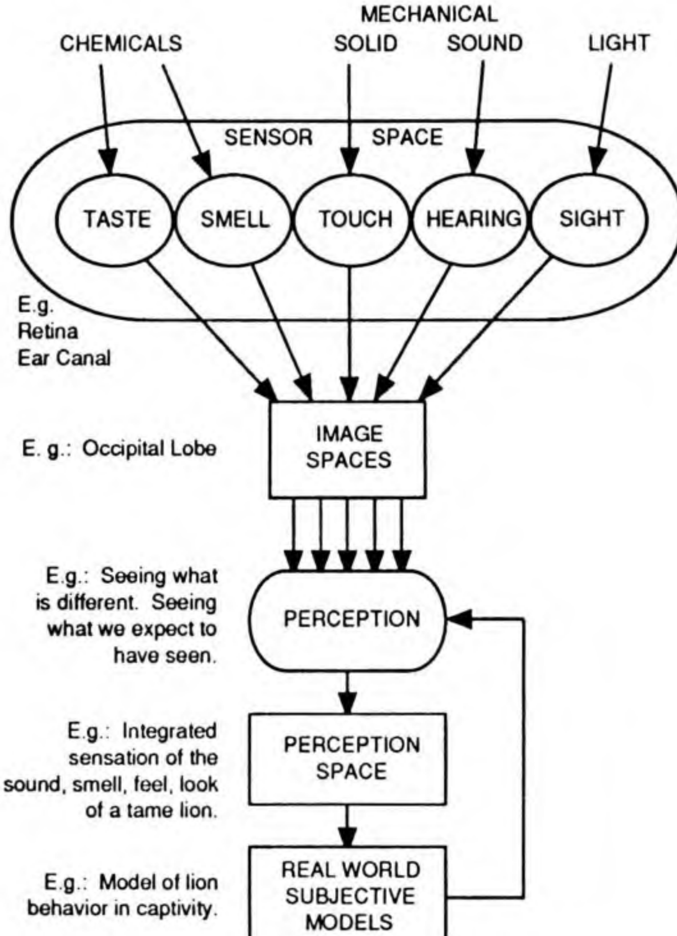
While Viscott's emphasis is on the pathology, the differences between disturbed and normal perception is only a matter of degree. Perception is subjective, based on experience.

Parlor games and training paradigms demonstrate limitations in the accuracy of human perception. First year psychology text books discuss the subject. Some of these lessons would be instructive adapted for demonstration in K-12 classes.

Exercise:

> Let students look at a complex photograph or a video tape containing activities that would be especially relevant to them or to a current lesson. Have them work independently answering a questionnaire about the scenes. Compare the results collectively and discuss perception.

Perception is a process that begins with energy impinging or action exerted against our senses. The impulses, called *signals*, generated by our senses pass through several stages of processing before we are conscious of the scene. This perception process is the subject of the diagram on the next page.



PROCESSES IN PERCEIVING

Figure 3-1

In this chapter, *Evolution in Science* will show first the richness of the signals arriving at our bodies from the environment. Then it will show how little of this information we collect through our natural senses. Next, the Strategy for Science Literacy shows that our experiences shape what we perceive. We save these perceptions in our memories as subjective models of the Real World. Since our processes are imperfect, so must be the subjective models of the Real World that we derive.

The Strategy sides with the Queen, observing how the human brain is capable of creating physically impossible models of the Real World:

> "There's no use trying," [Alice] said: "one *can't* believe impossible things."
>
> "I dare say you haven't had much practice," said the Queen. "When I was your age, I always did it for half-an-hour a day. Why, sometimes I've believed as many as six impossible things before breakfast." Lewis Carroll, 1865

Sometimes our models cause us to see what we expect to see rather than what is there.

> Besides the obscurity arising from the complexity of objects and the imperfection of the human faculties, the medium through which the conceptions of men are conveyed to each other adds a fresh embarrassment. The use of words is to express ideas. Perspicuity, therefore, requires not only that the ideas should be distinctly formed, but that they should be expressed by words distinctly and exclusively appropriate to them. But no languages is so copious as to supply words and phrases for every complex idea, or so correct as not to include many equivocally denoting different ideas. Hence it must happen that however accurately objects may be discriminated in themselves, and however accurately the discrimination may be considered, the definition of them may be rendered inaccurate by the inaccuracy of the terms in which it is delivered. And this unavoidable inaccuracy must be greater or less,

> according to the complexity and novelty of the objects defined. When the Almighty himself condescends to address mankind in their own language, his meaning, luminous as it must be, is rendered dim and doubtful by the cloudy medium through which it is communicated.
>
> Here, then, are three sources of vague and incorrect definitions: indistinctness of the object, imperfection of the organ of conception, inadequateness of the vehicle of ideas. ... Madison (H61)

This was written by James Madison under the shared pen name of Publius in the Federalist, paper number 37, between 1787 and 1788.

By these analyses the Strategy concludes that man is isolated from the Real World — insulated by the limitations of his senses, by his language, and by his mental models of reality. Science creates the solutions for this problem.

SIGNALS FROM THE REAL WORLD.

Energy and matter strike us from all around our bodies. Engineers and physicists also call these things *signals*. They take a wide variety of forms, including electromagnetic, gravitational, chemical, plus mechanical forms, including pressure, acoustic, heat, and texture.

Signals arrive at our senses from the source as fast as the speed of light. This speed is the limiting speed for all communications. Man's isolation from the Real World begins with this time threshold. If the sun were to explode, we wouldn't know about it for eight minutes. Another fanciful idea is that some cataclysmic event is currently overtaking our solar system from distant space, but we won't know about it for years. Finding superlatives for these fields is a challenge because so many adjectives have their roots in the reaction of our senses. For example, the Strategy dare not call the electromagnetic spectrum dazzling or delightful, though it promises both in its study.

Electromagnetic Signals

Electromagnetic (EM) energy has the peculiar property of acting sometimes as particles and sometimes as waves. Physicists can experiment with EM particles, causing them to react as continuous, undulating energy, called *waves*. As a result, Science has come to mix terms from particle physics and wave physics to describe the one phenomenon. *Wave* is a word taken from an analogy with acoustic energy and obvious mechanical motions like ocean waves.

Like acoustic energy, EM waves propagate through various media, but unlike sound they pass through empty space. In each case, propagation of the energy has a velocity that physicists can measure, a velocity characteristic of both the energy and the medium itself. Because this velocity is finite, experimenters can identify and measure a characteristic distance between similar points on the wave. This distance is the wavelength.

Exercises for young students:

> Measure the wavelength of standing acoustic waves on a vibrating string.
>
> Estimate the distance to a lightning strike by timing the difference between the light flash and the arrival of the roll of thunder. Use the speed of sound at sea level as a ratio to convert the time measurement to distance.

Energy will propagate in a medium at several wavelengths all at the same time. Physicists can measure the amount of energy in various bands of frequency or wavelength. The density[2] of energy according to either of these equivalent

[2]Density is also a key word, usually meaning a ratio of two parameters. The most familiar is weight per unit volume. Density is also the rate of growth of one parameter with respect to another. This may be a more general definition, referring to a distribution function. The EM spectrum is the rate of growth of power with frequency.

parameters they call the *spectrum*. It is wholly analogous to the familiar rainbow hues of the visible spectrum, energy spread by a prism according to its frequency or wavelength. In fact, physicists and engineers will sometimes use the word color synonymously with frequency, applying a word from the visible realm to other frequency regions.

Literally and figuratively, the electromagnetic spectrum is as vast as the universe. Electromagnetic energy bathes the earth from space. Natural processes generate measurable amounts of radiation from within the earth itself. Particles from the sun, distant galaxies, supernovas, and yet unknown parts bombard the earth with particles known as *cosmic rays*. (Note the use of ray, a continuous type of process, for a particle.)

Cosmic rays are a fruit salad of particles, some well known and some still puzzling. They comprise the highest frequency, or shortest wavelengths, known. They crash into the earth's atmosphere, setting off a chain reaction of disintegration and new particle generation. The result scientists call the *air shower*. It consists of the primary particles from space and secondary particles created by collisions. Similar particles also originate from the earth through radioactive decay of terrestrial materials.

Coming down the frequency scale, the same distant sources treat the Earth to gamma rays, X-rays, ultraviolet rays, visible radiation, infrared radiation, millimeter waves, microwaves, and last the lowly radio waves. At the high ends of the spectrum, physicists detect the secondary particles and their interaction with magnetic fields. Some of these collisions cause visible traces, as in the Northern Lights. Sometimes only the heat of the energy absorbed in the collision is detectable. At the lowest frequencies engineers detect *noise*[3] with their radars and hear static on their radios.

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[3]Noise is just about any kind of disturbance, including the din of traffic that might come to mind first. It includes static on the radio

At these frequencies, astronomers hear the hiss that physicists associate with the Big Bang.

In the midst of this EM shower from space is the visible spectrum. At low power levels, scientists measure visible energy as uncharged particles called *photons*. Astronomers use the visible spectrum to image the various objects in space — the sun, the planets, the stars, the galaxies, and even clouds of galactic stuff and our own atmosphere. Sometimes they work with direct radiation and sometimes they detect the absorption or reflection of visible energy in the background material. Each of the cosmic objects that radiates also has a characteristic absorption pattern in its atmospheres that gives us information about its compositions. Each has a signature rainbow.

Some important microwave radiation from space lies in the wavelength band of 18 to 21 centimeters, which man can detect with conventional radio telescopes. At much lower radio frequencies is the *continuum*[4] energy in the neighborhood of a million meters in wavelength. Being around a sixth of the earth's diameter, instruments that focus this wavelength can occupy a very large neighborhood indeed.

> Teachers should share simple examples of arrays with their students.

A compound eye like those of the fly or moth is quite likely a natural model of an array. Popular science books for children will portray the image space of the fly as a collage of replicated images of the Real World. That portrayal seems too improbable and too subjective in interpretation; it should be removed from texts or be fully qualified.

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and snow on TV, and these are about the most representative models of scientific noise. But in looking for a needle, a haystack is noise.

[4]Continuum here refers to this region in the electromagnetic spectrum below the lowest frequency of radiation that occurs when an electron changes energy from one orbit state to another.

Even if each image was much like the human view of the real world, the advantages of integrating the images into a whole for perception are too good not to have developed. Imagine that somewhere a fly might have looked at a human being and asked,

> "How can a human get around, seeing only two images of everything?"

Our brain comfortably integrates two distinct audio or visual images into a single image space with depth and angular discrimination. If the fly's tiny brain is analogous, it integrates his large set of images into a coherent whole image of the real world. If his perception isn't integrated, he must make some complex calculations, almost at the conscious level, to correlate his image with the Real World.

Except gamma rays, which are electrically neutral like photons, much of the high energy radiation from space is ionized. This means that the particles have electric charges. Alpha particles are positive, coming from the nucleus of atoms. Beta particles are negatively charged electrons. Some EM energy in our background, like the solar wind and the earth's magnetic field, shield the earth by deflecting and concentrating the charged particles.

In several ways, the gases in the earth's atmosphere also shield the surface by absorbing energy in the EM spectrum. As already noted, high energy cosmic rays are absorbed by collisions with various particles. Ultraviolet rays are absorbed principally by the ozone molecules, and infrared by molecules of water vapor in the atmosphere.

Except for a little bit of information provided by gravity, electromagnetic energy is the only energy that allows us to know of the rest of the universe. It's importance extends to all of man's activity, for it directly affects what we know of ourselves in so many ways. It allows us to communicate, to sense, and to measure. Archeologists and anthropologist know much of the history of life on earth because of Carbon 14 dating. That Carbon 14 was created by the continuous action on carbon 12 atoms of electromagnetic energy in the form of cosmic rays. Geologists can validate models of the motion of the earth's crust by deciphering changes in the orientation of naturally occurring permanent magnetics.

Gravity Signals

Man's understanding of gravity is still in its infancy. According to Isaac Newton, gravity is a force, acting instantaneously over any distance, an idea that troubled many physicists. Newton's model is adequate for all practical purposes here on earth. In the Newtonian sense, the sum of all the gravity forces in the universe is likely the phenomenon that gives mass its inertia. However, Einstein said instead of gravity being a force, it could be modeled as a distortion in the time-space continuum caused by massive bodies. Whew! Not only that, but he validated it by telling astronomers to look for a shift in star light passing close to the sun. Next eclipse, they did, it did, and many came away convinced!

Strictly speaking, gravity is not energy. It has the dimensions of an acceleration, while energy is the product of force and distance. Students in K-12 should be learning about the close relationships like these between dimensions and parameters.

Experiments are underway to detect gravity waves theorized to propagate through intergalactic space. Used this way, gravity is in the family of signals or energies. In any interpretation, gravity is a dominant factor in every environment. Whether or not it is a signal, it provides a local sense of direction critical to life forms on earth, and more. It is the force or acceleration that provides physiological equilibrium. It provides animals with their kinesthetic sense, the ability of the animals to sense motion.

Chemical Signals

A synonym for delightful is palatable. This might apply to the chemical traces in our environment that give rise to our senses of taste and smell. Chemical particles become signals by virtue of being carried in the air, in the water, and on the various substances that we can touch. They are organically detectable at very low concentrations by electrochemical reaction with chemically matched receptors in the sensory tracts. These processes of taste and smell surprisingly have earned the name *chemoreception*. In various mechanical ways, the air and water that vector the particles to our senses also act as filters limiting, biasing, and masking our chemoreception.

Acoustic Signals

Acoustic waves are mechanical disturbances in solids, liquids, and gasses that undulate in, again, what science call waves. The waves arise because the source of the disturbance has elasticity. The mechanical energy that first disturbed the elastic matter causes a vibration, exchanging energy alternately between

* potential energy in the form of compressed matter,
* kinetic energy in the form of expanding matter,
* potential energy in the expanded matter,
* kinetic energy in the compressing matter, and
* back to compressed matter again.

This motion propagates from the source through the medium, whether or not the medium itself is elastic, or compressible. This exchange of energy between stored elastic forms and dynamic motion in the source has the name *simple harmonic motion*. That energy couples into the medium which carries it into space.

A single mechanical disturbance will produce a whole characteristic spectrum of intensity, where spectrum is one form or another of the distribution of energy by frequency. The mechanical disturbance shapes the spectrum initially. Then parts of the spectrum are absorbed or reinforced by the resonant characteristics of the source and propagating media.

Thunder provides an excellent example of an acoustic signal shaped by its medium. The original burst is an extremely short, high intensity release of mechanical energy as the heated and ionized air collapses around the spent lightning bolt. The name *clap* of thunder points to that sharp crack of sound when it is nearby. To engineers and physicists, an approximately instantaneous release of energy is an *impulse*. This is an idealized mathematical function, infinite in amplitude but lasting no time at all. Thunder approximates an impulse quite closely at the outset, but so far scientists have found nothing infinite in nature. This near-impulse creates *white noise,* so named because every frequency (or color) is present with about the same energy. In terms of the spectrum, every frequency is present in equal amplitude. Since white noise is also a mathematical idealization, possessing as it does every frequency out to infinity, it is only approximated in nature.

As the report of the thunder propagates away from the lightning strike, space and the atmosphere attenuate and filter the sound. Energy couples from the thunder to the atmosphere, which is roughly speaking resonant at low frequencies, causing a filtering action. The air has enough elasticity at the low frequencies to get in synchronism with the thunder. This effect, along with reverberation and attenuation of the high frequencies gives distant thunder the reverberant, low frequency effect known as rolling. The loss of high frequencies through the air and into the ground removes the sharp edge of the initial, short burst of the thunder.

Reverberation of the thunder is more pronounced when a dense cloud cover is present. This changes the tuning of distant thunder. Armed with this information, our amateur scientists in K-12 can listen to thunder with discrimination.

Touch.

The classic pedagogical demonstration for touch may be the temperature soak test. It demonstrates not the influence of our general experiences on perception, but rather the effects of immediate conditioning on our senses.

> Let each of the first group of students soak one hand in a bucket of ice water while each of a second group soak one hand in hot water. Then have them test the temperature of a bucket of water at room temperature with the conditioned hands. What do they feel? What

is their subjective opinion about the feeling of the room temperature water?

All information is conveyed by a transmission of energy. In the hand soak experiment, heat is the flow of energy. The difference between the sensations of hot and cold is just a change of direction for the energy flow!

In other touch experiments, work is done against the nerves in the body. Here is a way to demonstrate this effect.

Place materials of different texture on the body, such as sandpaper of different grits. The bare back might be a good place to start to avoid visual clues. The hand is not good because of almost imperceptible motions and extreme sensitivity. Have the students describe the sensation with no motion of the material, and then with slight motion.

Other signals

Are there other signals in our environment? Science knows of none. The following suggest other worlds and other means of communicating:

* spiritual world
* extrasensory perception
* sixth senses
* clairvoyance
* the occult
* mind reading
* telepathy
* spirits

None of these has revealed itself to confirmed measurements, so they are hidden from the objective world. Scientists, but not science, can deny their existence. To science, they are simply outside the realm — not there. The mysterious are a mystery to science.

SENSING REAL WORLD SIGNALS

Physicists dedicate whole careers to sharply focused studies of things our bodies cannot perceive, like neutrinos or a small portion of the intergalactic cosmic rays. These are but two examples of electromagnetic forces that produce no effect in our natural senses. Except for electric and magnetic fields, science has no evidence yet that any other creatures sense EM phenomena either.

Vision

We detect and appreciate the beauty of the visible spectrum, nominally stated as 4000 to 7600 Å[5]. We also feel radiant heat in the form of infrared energy, which every object emits, depending on its temperature. If a source is intense enough, infrared energy as long as 10,500 Å can is perceptible by humans as light. Every wavelength, every sensation, has a characteristic threshold for detection.

The high energy sunlight that soaks our environment correlates with our keen sense of sight and with our bodies relative imperviousness to energy in this band. The fact that visual images are sharp is not fundamental to electromagnetic energy, but is due primarily to the wavelength and to way we create images. Any of the energy from an isolated source could be collected and focused to a sharp image with a big enough lens. The area of the lens is the *aperture*. This aperture must be large to collect enough energy when it is sparse. The ability of the lens to focus on an image depends on its span measured in wavelengths. So, the lower the frequency, the longer the wavelength and the larger the antenna must be for sharp images.

Coherence. If technicians take care not to introduce distortions, they can combine signals from two or more widely separated collector elements at the same time. Having the elements separated by many wavelengths, the technicians will not capture the energy that falls between them, so they forego some sensitivity. However, applying this method enables them to measure with more accuracy and to improve their ability to resolve sources from one another. Signals added this way are *coherent*, while antennas linked this way are *arrays*. Engineers use the array principal every day in

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[5]Å is the symbol for Angstrom, a unit of distance equal to 10^{-8} centimeters.

antenna design for electromagnetic and acoustic receivers and transmitters. They hook up a whole array of telescopes, radio antennas, microwave elements, or microphones. They add their outputs coherently to make them act as a single, extremely accurate telescope, antenna, or microphone.

The way that coherence is first broached in upper division college technical training, it is a subtle, complex concept. This is unnecessary. It is simply the reinforcement of phenomena that repeat themselves and the lack of reinforcement of things that don't repeat. It is the essence of comprehending patterns, and is readily taught to youngsters. A demonstration appears in Chapter 5 as the Twos Experiment.

Color vision. Human vision is not sharp in the blue region because of color aberration. This is a result of the prism-like separation of light into its components by the lens. The human eye is like a camera, and it would have to be much more complex to have wide band color correction. The complexity inherent in color correction may be a contributing reason for our failure to have evolved an ability to sense UV light.

The lose of human visual acuity in the blue region is evident in this classroom demonstration:

> Show students a string of various colored holiday lights, having them observe the fuzziness of the blue or lavender lights.

Few other animals have color vision, but some have other advantages that we don't. The eagle's eye is remarkable for its telescopic vision. Man, like other predatory animals with eyes located dominantly in front, have binocular vision that yields excellent depth perception.

> Have children discuss the differences in eye placement between different animals. Note that hunters have binocular vision, and prey have field of view. Why?

Ultraviolet

Between the visible spectrum and the X-rays are the ultraviolet bands of about 100 to 4000 Å. The sun emits energy in all these bands, but only light the near UV band, 3000 - 4000 Å reaches the surface of the earth. Man can just perceive a blue glow in the near UV band down to about 3500 Å. The shortest wavelengths of the near UV, up to about 3100 Å, are the cause of sunburn, which correlates with the incidence of skin cancer. Perhaps man's senses did not develop to detect the UV because our normal exposure level is low or because our life expectancy had been much shorter than the typical development time for skin cancer. Undoubtedly animals have good UV vision for some butterflies have markings that identify their species but only in the UV. Also bees use near UV reflectance to identify and locate flower species.

Infrared

For self-protection, we need to detect hot bodies and this we do by sensing their infrared radiation on our skin. Correlations like this may point to Cause and Effect, but that is not provable. Pit vipers have infrared sensors that enable them to locate prey in the dark.

X-rays

Bracketing the visible spectrum are the X-ray and the microwave bands, which man has harnessed in many beneficial ways. Energy in these bands does not occur naturally in our environment to any great extent. Perhaps this is why our senses do not respond to this energy, even though the cells of our bodies are vulnerable to them.

Certainly the converse is true: if these energy forms were abundant enough in the environment, we would not be here today with our present senses. Microwave energy can ionize and heat our body's cells, destroying them. The same process occurs in foods in the microwave oven.

We are also vulnerable to X-rays. They can destroy tissue through ionizing and burning. They also cause genetic deformities and initiate malignancies by changing our DNA and causing cells to mutate. No animal species exploits these bands.

Electric and Magnetic Fields

Certain migratory birds use the earth's magnetic field for navigation. This gives new meaning to the phrase, animal magnetism. Some fish, in particular sharks and eels, sense electric fields. Some may detect the interaction between electric signals and the earth's magnetic field. These senses are rare in the animals, and nothing comparable exists in man.

Smell

Compared to the animals, man has a poorly developed sense of smell. Dogs can learn to discriminate between objects by odor where man detects no odor at all. Fishes have well developed senses of smell that operate in salt water or fresh water, where man detects nothing.

Hearing

On the high frequency side of acoustic signals, man's hearing normally ends between 20 and 25 Kilohertz. This is well below the limits of dogs and other animals. Our domestic dogs and cats also have trainable ears that they use to find signals by searching for the direction of arrival. Man does a similar thing by moving his head to find the source of a sound. This is *dynamic localizing.*

Man relies as much on three other processing methods for finding the direction of a sound source. These methods use both ears, so they are called *binaural.* The methods also work with a stationary head, so they have the name *static localizing.*[6]

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[6]The methods are phase detection at low frequencies, difference to sum ratio detection in the mid-band range, and time of arrival discrimination for high frequency signals.

Classroom experiment:

> Ask children to find the source of a sound in a room. If a high frequency signal, say greater than 8 KHz, is suddenly switched on, they should be able to find the direction of the source easily.
>
> Conversely, gradually increasing the sound level until it becomes perceptible will make it quite difficult to localize. Head tilting will lead to false directions caused by echoes within the room. The sound will appear to come from several points in the room.

Dynamic Range and Passband

Of this panoply of signals in which we live, man senses but a small portion. For those energies that we can detect, each sense is a filter, reacting to just a portion of the Real World. We have lower and upper limits to every sense. In the frequency parameter, this span of energy is the *bandwidth*. Like every other creature and technology, man is also bound by power levels in signals. We can't sense signals too weak and we have various difficulties with signals too strong. This intensity region is the *dynamic range* of our sensors. The region where our senses operate successfully is called the *passband*.

We have additional limits in the parameters of concentration (parts per million, for example), contrast, depth perception, localization, and others. Our sensors have limitations in resolution as well. We may be able to detect a single object, but two objects closely spaced can confuse our senses. Limitations like these are in all sensors in all animals, and in the analogous transducers in technology. Later the Strategy will develop the idea that one of the objectives of technology is to extend our senses into the Real World, sensing at a distance or expanding our limitations in dynamic range, bandwidth, or any other parameter.

Classroom experiment:

> Have students stare straight ahead with a VDT terminal about 45^{0} to the side. Do they see it flicker?

Stare above and below and all around the display. Where does he see it flicker? Why is it so?

And another simple experiment:

Have the student gently rub his fingers together alongside his head to make a whispering sound. Repeat in front of the eyes. Why can he hear it to the side and not to the front?

So, man samples only a small part of his Real World environment. Our eyes and ears do not sense uniformly everywhere. School can create a natural awareness in our children during their formative years that the Real World projects onto our senses with something much less than perfection or completeness. Our image space contains a projection of the Real World. This is analogous to the two dimensional image of a three dimensional scene formed in a camera. It is readily amenable to demonstration for the K-12 student.

A pedagogical hint of an experiment:

Set up a street scene with building blocks. Photograph it with a video camera, and display it on a TV screen. Give the children a ruler, & have them measure the distance between a pair of buildings. Then measure the distance between the images (projections) of the same two buildings on the screen. Discuss. Move the camera, repeat the experiment. Discuss what changed and why.

This experiment works well with a monochrome camera with colored filters added. A colored scene projects differently depending on the filters used.

Teachers should develop a curiosity in their charges about what is out there, how they can sense it, how they can be precise about it, and how they can share it.

Pedagogical experiment:

Make spectral plots of portions of the electromagnetic and acoustic spectra. Show the areas of sensitivity of

> different sensors of man and the animals. On each spectrum, show the location of energies from different sources.
>
> In the early grades, use a chart of the piano keyboard as the abscissa[7] of spectrum. Let the K-1 student match the frequency of a guitar or an ocarina to the piano keys. Let the students make a one string base viol, locate it on the real piano in frequency. Retune it and locate it on the spectrum. Map it on the picture of the keys.
>
> As the student advances through the grades, expand the spectrum.

PERCEIVING REAL WORLD SIGNALS

Sight is probably the most well developed of man's senses. Still, the image formed on the retina of the eye, which the Strategy calls the sensor space in Figure 3-1, is a small part of the whole image we carry in our brains.

Perception Space

The human constantly scans with his eyes, both on a small scale and on a large scale. The large scale scan creates an extended image in the brain of his immediate environment beyond that formed on the retina. That larger image, the Strategy calls the image space. The eye refreshes this scene at different rates, depending upon the individual's training and concentration. Perhaps the compound eye serves the same function as scanning of the eyeball in its socket.

Here's a simple demonstration to show students the difference between their sensor and image spaces:

> Have the student sit quite still while staring at a single spot in the room. He will observe that his image of the world around him shrinks.

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[7] The abscissa is the x-axis. See the pedagogical exercises in Chapters 5 and 6 for a full review of elementary graphical terms.

Perception is our awareness of the images that we form. How man reacts to his image space depends upon his mental processing. The brain integrates the five senses into a general composite perception space. The perceived scene depends upon the individual's training and experience, upon the models of the Real World that the viewer has developed or learned.

Generalization

The human has a mental model that enables him to discern novel features. The process of discerning also contributes to updating the models. Through a process called *generalization*, we modify our mental model to accumulate the differences. In comparing the perception space with the Real World, we strive to extract what is different. As a student aircraft pilot gains experience, he will scan his cockpit more and more efficiently. Soon he will notice only the gauges which are out of the ordinary.

Sometimes this process works to keep us from creating an accurate perception space in the first place. Sometimes we fail to detect differences, especially when the scene isn't very important or when our concentration is elsewhere. Our brains fill in from the model. Thus we tend to see what we expect to see. An overworked example is the following:

> Were you able to read this
> sentence correctly on the
> the first try?

This phenomenon distorts our perception. It has caused some of the worst possible consequences for aviators.

Intuition

When asked, "What is your intuition?" the scientist would understand the question to mean, "Based on your professional experience and knowledge in science, what do you think is happening, (will happen, would happen, etc.)?"

By the dictionary, intuition is knowledge marked by the absence of reasoning. In the example just above, intuition has more the sense of insight, specifically, knowledge gained quickly through intellectual processes without resort to experimentation. In this way, it is more or less à priori knowledge, arising from reasoning. Insight carries with it a sense of suddenness, a quick perception and understanding. Scientific intuition is or can be more studied, hence more reasoned.

Insight makes the practice of science efficient. It helps the creative processes, as in the creation of models or design of experiments. It accelerates the linking between Cause & Effect. It provides tests of reasonableness when a scientist first formulates his hypotheses. It provides a check for the thought experiments so important in science.

Sometimes a scientist mentally generalizes a pattern from a foreign discipline into the field in which he is currently working. Sometimes this sort of cross-disciplinary extrapolation transplants Cause & Effect relationships in nature. Sometimes it applies to the specific method by which a study pursuit might be successful. These are the intuitive processes that experience brings to efficiency in Science. When this sense is too strong, it blinds, which might account for the disproportionate contributions from younger scientists.

MENTAL MODELS.

From this reasoning, the Strategy concludes that the mental model each of us carries of the Real World is far from perfect. This mental model is not just the perception space, but the collection of all that we think we know about the Real World.

Not only are the models flawed, but the brain is able to conjure physically impossible concepts. Scientists call them *physically unrealizable*. There are simple, practical examples, like the idealizations of Euclidean Geometry including the point, the line, and the circle. More exotic examples include those creations of the Dutch artist M. C. Escher, who illustrated delightfully impossible ideas on paper and canvas. Escher was the visual partner in the Hofstadter troika of Gödel, Escher, and Bach.

Escher imagined physically unrealizable worlds. He made a perpetual motion aqueduct, a two dimensional image of a four dimensional staircase, and hands drawing one another.

Pedagogical value:

> Escher's pictures should be on display in the classroom to invite discussion. The pictures delight people of all ages. The teacher need only ask, "What's wrong with this picture?"

Impossible Dreams

Our language and our logic allow such things to exist in our imaginations, even when they violate other models of the real world. Our logic allows us to imagine things which cannot exist. We hold images of both possible and impossible worlds. We could even add a third world of our dreams and a fourth of our fears. To make things much worse, our possible worlds are subject to frequent errors.

A serious example is negative time.

Classroom exercise:

> A 12 minute Wylie Coyote cartoon or an old Tom & Jerry can provide a delightful excursion into the models of physics violated. What do our models tell us should happen when the coyote first carefully lays out a fulcrum and a lever under a boulder, then jumps on the lever to launch his missile? What is Cause? Aren't we certain of the Effect? Our models have waived away a whole raft of assumptions through idealization.
>
> Instead, nature changes its laws to work against the pitiful coyote. In scene after scene, the humor lies in the unexpected. The lever breaks, or turns elastic. The boulder is the tip of a larger rock that the coyote is standing on. The boulder stays put and the fulcrum collapses. The boulder crumbles. Or it launches in a completely unexpected direction. Get the children to speculate on what direction it should have gone or

might go in the next cartoon. The expected outcome is our mental model.

An analysis of what is funny can be most instructive and it contains a lot of science. Stop action and instant replay will prompt a lot of attention and participation.

Self-referencing

Hofstadter ties the various Escher paradoxes together with an analogy to self-referencing systems. He points out the beauty, if not the science, in these entertaining analogies. Russell & Whitehead in Principia Mathematica addressed earlier problems with self-referencing logic. They first typed logical statements and then insisted on a clarification between sets and members of sets.

Later Kurt Gödel, the scientist member of Hofstadter's troika, nearly destroyed mathematicians. They had been seeking proof of self-consistency within their mathematical models of the Real World. Extrapolating from this problem with self-referencing, one might look for a theorem that says that a human brain can never understand itself completely. If it could, it would be self-referential.

When we are very young, we perceived little because our subjective models were immature. As we age, our models dominate our perceptions more and more. This happens whether we acquired them subjectively or learned them objectively. In one view, the increasing importance of our mental models in perception might reflect the onset of rigidity in thinking with age. Conversely, it may reflect the reality that one data point in a few is much more significant than one data point in many. The retarded mind, the normal mind, the creative mind, and the aging mind each has a different way of creating and using mental models.

Language limitations.

The naturally occurring power of language and its imbedded logic limits man's ability to model the Real World. A thought does not require much complexity before verbal descriptions become unwieldy. The strategic placement of a few parentheses can drastically alter the meaning of otherwise accurate oral sentences. The sudden switch in contextual relationships is the foundation of much of our comedy. Precision in language which characterizes good science is likely the cause for a reputation of humorlessness in science. Actually, the humor is there but at a much more sophisticated level.

As humor arises from misplaced relationships, it has foundations in misapplied logic implicit in our languages. Conventional logic is *binary*, meaning that is has two value states, true and false. The Law of the Excluded Middle, which says that there is no other value state, can be a theorem. Whether it is a theorem, an axiom, or a rule for proofs is a matter of choice in the construction of the logic. It is present in all practical logics. An object is either at rest or it is not at rest, that is the Law of the Excluded Middle. How could it be otherwise? How can light be both particles and waves?

Fuzzy logic is a research field in which mathematicians place degrees of truth on statements by assigning probabilistic weights. In the end, though, the scientist must put complex concepts into mathematics. The result has been mathematical expressions that are all but unintelligible.

Non-linearity

Science has advanced to the state today in physics and mathematics that uncertainty may be growing faster than certainty. Our mathematical models are most tractable and most mature at the linear level. These models, though, have to be a minuscule share of what is possible with non-linear representations. Almost every physical system studied becomes non-linear when probed deeply enough. Mathematics is in its infancy in non-linear modeling.

Earlier, suggested experiments in non-linear systems including calibrating a cheap weight scale and calibrating a VCR counter. More advanced problems in non-linear systems include the troublesome gravitational attraction of more than two orbiting bodies in space. This problem like most in nature is non-linear. Nature continues to unfold its many complex processes at a dazzling rate before our rapidly expanding horizons.

A good pedagogical analogy:

> A problem somewhat akin to the three body gravitational problem is the double pendulum. Enrich the young student's environment with a physical model of a double pendulum . Its motion is entertaining and unpredictable. At higher grade levels, students can measure its performance for analysis.

The Brief Glimpse

Yet another aspect of our individual and collective reality is that we sample the environment on a narrow slice of time and space. Most of what people think of as constancy is a flux of change sampled too briefly. What is 100 generations in 100 million? What is a lifetime in an eon? Natural processes occur on time scales too small and too large for our perceptions and instruments. Others occur on a distance scale too large and too small for us to appreciate or resolve. Science and technology work continuously to expand both horizons in both directions.

Mental Development

Each of our senses may be inferior to some sense in some other part of the animal kingdom. Yet no other animal could have as highly developed a model for the whole of the Real World. Our machines have yet to come up to the state of multisensor integration exhibited by the human brain. This is a fruitful area for future careers in biology and engineering as science and technology expand our perceptions through sensory integration.

Researchers are beginning to discover how the brain distributes knowledge in overlapping networks. In other ways, we find our brains distinctly partitioned into functional areas with some kind of a hierarchical control center. Perhaps each functional area holds its own model of the Real World. This might be true if the organization of the brain is functional, whether or not the functions are spatially partitioned. In either model, the hypothesized control center would integrate the various models into a whole.

Science is just beginning to understand how our brain works at the information level. Engineers have made progress in neural networks, but this is a fledgling technology yet to produce its first major result. Engineers can build large, simulated neural networks. They can model them at the microscopic scale, or in gross statistics, but they don't know yet how they work at the scale of understanding. Information scientists have no idea whether a particular neural network will converge[8] to a solution on a specific new problem.

Science has yet to understand how the brain develops its operating system, to borrow a word from computer science. As adults, our brain operating system continues to function above our conscious level. Good examples include sleep and the dream process. Presumably these promote the health of cerebral processing, and deprivation experiments support the thesis. However, physiologists understand the processes poorly, although they have been strongly associated with activity in the frontal lobe of the brain. Perhaps the conscience is an imperfect little supra-routine watching over our conscious activities.

There needs to be something to get the young brain started learning. The young brain needs an instinct or something innate or genetic to drive it to acquire perception, language, generalization, and self-awareness. Perhaps with maturity, this operating system switches off growth in these four areas so that the brain can get on with its primary functions.

Receptiveness to Language. Many observers have noted the differences in receptiveness of the human brain at various

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[8]Converge meaning actually get there!

developmental stages. A pioneer in the field was psychologist Jean Piaget, who suggested the following five primary phases of development shown on the next page.

Piaget's classification system is abstract and is his generalization of normal development as he assessed it. He does not say what happens if a child is deprived of instruction or opportunities at any particular level.

Some researchers have discovered irreversible learning disabilities when children experienced early deprivation. Malnutrition, and especially iron deficiency, has been shown to cause irreversible cognitive deficiencies, meaning that restoring the diet does not correct the losses. (See S91). The irreversible nature of the problem suggests either that the body loses its ability to metabolize and use the restored nutrients in the brain, or that the development opportunity itself within the neurology of brain has atrophied. Experiments with animals confirm this theory of atrophy. Experience with less pathological cases, that is, from retraining individuals only deprived of the early training, also would indicate that it is the neurological opportunity to form abundant useful pathways that is lost. This is the basis for some of the training recommended in this Strategy.

Children, then, readily learn certain skills in the early years, even before Kindergarten. The opportunity stays with

them for a time, and then, if the hypothesis above is true, decays rapidly. An opportunity lost to exploit some stage of an individual's physiological development may not be recoverable. It may be capacity lost — mental development forever handicapped. One can have the greatest empathy for adult illiterates and the effort that they and their teachers put into learning to read well beyond their years of receptiveness.

Piaget organized his observations into five highly generalized stages. The California Science Framework identified specific

STAGE	AGE	NAME	DESCRIPTION
1.	to 1.5	Sensimotor	Infant stage. Pre-speech. Perceives objects in groups, as rings, networks. Assembles (adds) and disassembles (subtracts) objects.
2.	1.5-3	Primitive Reasoning	Kinetic muscular intelligence, i.e. infant thinks with body. Language added with capacity for symbols.
3.	3-7	Preoperational	Elementary thought experiments model thinking with body, but absent Cause & Effect.
4.	7-12	Concrete operational	Thinking augmented with physical objects. Abstract thinking limited to notions like "responsibility". Elementary concepts of integers, series, 1-to-1 correspondence, classification, space, time, speed. Receptive to concrete teaching with activity, but not verbal instruction.
5.	12 up	Formal operational	Pure abstract thinking develops. Receptive to verbal teaching.

PIAGET'S DEVELOPMENT STAGES
Table 3-1

cognitive tools[9] appearing on a somewhat different timetable. The scheme here is less abstract than either, identifying instead specific skills or training subject matter. On the next page is a diagram of this Strategy's tentative conjecture about stages of mental receptiveness, compared with Piaget's scheme. Note the logarithmic compression and that the windows are tapered to suggest uncertainty about the time tables between individuals.

Vision is one of the first skills to develop in the formative brain. The infant learns to recognize objects in the visual field as one of its first tasks. Denied this experience, a child is permanently handicapped. Experimenters have demonstrated this phenomenon with laboratory animals. In a specially interesting case, physicians restored the sight of a man in middle age with tragic consequences[10]. Maximum receptiveness to languages follows shortly after visual perception, lasting possibly into our teens.

The K-12 educational system should capitalize on the natural physiological timing of development. The suggested method is not a synchronizing of the curriculum with some theory about precise or standard developmental stages. It is distinctly different from any attempt to fit children into a developmental norm, or to shape the curricula to match some theoretical standard profile for acquired knowledge. The classroom should be a broad opportunity, with the child judged not on some absolute level of acquired facts, nor on his enthusiasm and participation, but, if feasible, on his intellectual growth during the period. The idea is to provide a

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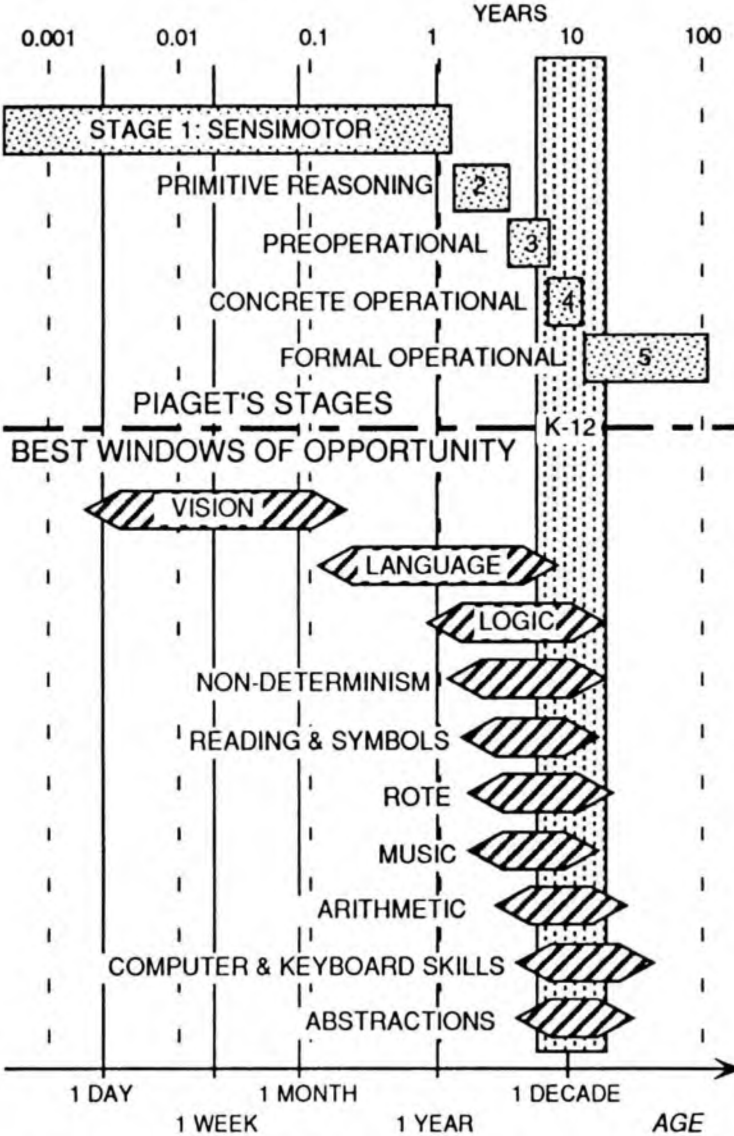
[9]Specifically, they are observing, communicating, comparing, ordering, categorizing, relating, inferring, hypothesizing, designing experiments, predicting, conceptualizing Laws of Science, applying, decision making, and making value judgments.

[10] He left a record of increasing perceptiveness in his drawings. In the end, while he had learned survival as a blind man, he could not cope as a sighted man and he committed suicide. See Restak (R79).



MENTAL SKILLS ACQUISITION MODEL

A CONJECTURE

Figure 3-2

language-enriched environment for each pupil to exploit as he becomes receptive.

The list of mental skills in the diagram and discussed above contains a substantial amount of speculation. Each might occupy a different part of the brain. Most of the skill areas occupy accepted classical partitions of the brain, such as a speech center and the occipital region for vision.

Personal experiences of the author point to separate skill areas for rote learning and non-deterministic thinking. For example, twice learning to play the piano keyboard under different methods showed the involvement of different parts of the brain with learning music. Independently, one can learn to read music in general, learn to read a specific composition, and learn to memorize compositions. A music student needs exercises in all these techniques plus several others[11] to be a complete musician.

Educators debate whether to teach cognitive skills as opposed to memorization. This Strategy suggests in its model that these skills are independent and interdependent. A fully developed brain will use its various skills to cross-check one another, building itself a more complete model of the Real World. This constitutes intuition and insight. The Strategy urges the deliberate development of these skills. The recommendation is to exploit efficiencies available during the early receptive years. Conversely without this training, specific abilities are likely to atrophy. At later stages, these skills will be irretrievable for all practical purposes.

The competition between thinking skills and memorization include

sight reading	vs.	phonics
recitation of tables	vs.	problem solving
recitation of verse	vs.	reading
vocabulary	vs.	experiences

---

[11]E.g., learning to transpose, learning to harmonize, learning composition.

The argument of this Strategy is that these are not pedagogical choices. Instead, the educational system should teach both and it should teach method. The real issue is the time available, and this puts the designer of curricula and class room schedules to the test.

A related aspect of this Strategy is to provide experience before theory. Piaget recognized the need for a crutch of experience in his Fourth Stage, Concrete Operational. The word crutch is a pejorative used by some who may be anxious to free the student for theoretical training. Having a practical example, though, helps learning the most abstract ideas of the most advanced mathematical concepts that one will ever encounter. A few students will not have need of the experience, but it never hurts. Everyone who wishes to teach should have practical examples in his bag of tools. Sometimes when the teacher's training has been only theoretical, the practical examples are difficult to find. The Strategy argues that not only is the student better prepared with experience before theory, but that the student benefits in scientific training by seeing for himself the emergence of patterns that are perceptible only with increasing personal experience.

Psychology introduces Laws of Association, which attempt to express what is happening in the brain when a word or idea triggers a chain of thoughts and images. Two such laws seem to have endured: the Law of Association by Contiguity and the Law of Association by Similarity. They are roughly equivalent to Pavlov's concepts of conditioning and generalization, respectively. Pavlov's words help define the meaning in the laws. The empirical foundation recommended for theory in this Strategy may satisfy the Law of Association by Contiguity. As Pavlov made a link between a physical stimulus and a mental response, the Strategy makes a link between the concrete and the abstract. The Law of Association by Similarity the Strategy places in the lesser models of generalization within the Scientific Method, discussed further in Chapter 6.

Immersion in Languages. Schools should immerse students in languages as soon as the schools have access to the children. Immersion in this Strategy means making language the first priority, the real subject matter or hidden agenda, in each track. When teaching early mathematics, social studies, or history, teachers should grade progress on the acquisition of language skills. They should judge students on their progress in capturing vocabulary, syntactical rules, and pronunciation. The only way to improve on this notion is to begin the experience earlier, such as one or two years before Kindergarten.

A child in the U. S. deprived of rigorous training in English, the international language of science and technology, is a child cheated. The prioritized language training program recommended in this Strategy is

(1) English
(2) a contemporary foreign language,
(3) at least one of the classic languages,
(4) a technical vocabulary, and
(5) one robust computer language.

For the foreign language, Spanish is preferable in much of the United States because of the demographic trends. Conversely, never teach Spanish as a primary language in this country. English is too dominant in science and commerce, and the technical literature in Spanish is too sparse.

As a beginning, scrap the politically popular experiment of ESL (English as a Second Language)! If Kindergarten students are not ready in Standard English, put more effort into primary English language training, not less. The ostensible argument for ESL and bilingual programs for minorities is to maintain subject matter training for students weak in English. This policy ignores the reality that English itself is overwhelmingly the first priority subject matter. Technical vocabulary in the schedule above includes mathematics, physics, chemistry, and biology. For the computer language, C-language might be the first choice today.

As the Strategy claimed above,

> Man is forever isolated from the Real World —
> insulated by the limitations of his senses,
> by his language with its imbedded logic, and
> by his mental models of the Real World.

Do we give up? Of course not. We have the communications and intelligence to link our brains together through objective structures. This raises our knowledge to entirely new, higher planes. This process is called *Science*.

CHAPTER FOUR
SCIENCE IS KNOWLEDGE

WHAT IS THE DEFINITION OF SCIENCE?

Exploring the isolation of man from the Real World provides foundations for what science needs to be and to do. Excursions into the limitations of human senses, the brevity of our opportunity to observe the Real World, the small space we occupy in the universe, and the unreliability of our perception processes indicate how science can bring together a variety of observations into a whole. They also point to the nature of what science must be to serve our needs.

As the objective branch of knowledge, science overlaps other branches of knowledge. Science is neither just technology nor mostly laboratories. It is not simply the working environment of scientists, but is pervasive and universal. It stands on its own, not as an alternative or competitor to particular schools of thought or belief, but as a companion to all forms of knowledge. Science embodies at least two related, underlying articles of faith: Explanation and Cause & Effect. These concepts are rich in subjective undertones, requiring clarity in the definition of proof so that one can decide if anything is a proof.

The Strategy must define Science so that it excludes all "isms". A simple analysis of the needs leads to a constructive definition of science that draws from the best of the various schools of philosophy. It successfully severs science from the controversy and peculiarities of a whole raft of past and future belief systems.

With this background, the Strategy for Science Literacy evolves a pragmatic definition of science. At each step, it must be consistent with the views of practitioners, and, with luck, of educators. It begins with the question of basic purpose, to explain or to describe, and concludes with something else. Then it offers a set of axioms which work like those in mathematics to connect knowledge to the Real World, but at the same time free the practice of Science from the traps in the philosophy. With the stage set, the Strategy settles on a novel definition of science composed of generally conventional ideas. The process and the chapter conclude by measuring the Strategy's ideas against the writings of Stephen W. Hawking, the renowned modeler of Hawking Radiation and Black Holes. A brief epilog discusses randomness in science and offers a comparative set of strategic elements for science and science education.

TO EXPLAIN OR TO DESCRIBE?

Philosophers debated the role of what became science, even before they invented the word. Schools of thought formed around the subject, including Empiricists, Positivists, and Rationalists, to name a few. "Which is science supposed to do, explain or describe?", they asked. The Strategy claims that neither is sufficient or appropriate.

Definition of To Explain

A few words need to said about the word *explain*, for it has a variety of meanings. In some senses, it means simply to *clarify*, as when a writer eliminates obscuring, extraneous language, or makes the logic more evident. In a related manner, *explain* means to put into context with previous theories or expositions. This is *explanation* in a narrow sense. The process can involve putting prose into symbolic form, showing the mathematical formulas that underlie the prose, and doing a little comparative analysis between related theories. As used here, this kind of explanation is a reference to precision in language and to model development. These are essential parts of a scientific effort. As important as these steps are, they constitute too weak a form of *to explain*.

The broader definitions of *explain* extend the ideas of clarity into the subjective world. Instead of just making an exposition less obscure, the definitions add ideas of acceptance and understanding of the exposition on the part the listener. In this sense, *explain* means to make clear to the senses, to make evident or manifest to the understanding. It means to discover, even to prove, Cause & Effect relationships. Some have called this Causal Explanation. In this sense of Causal Explanation the Strategy claims that the philosophical debate has not been well-formed.

Things that Explain or Describe

The problem is that any religion or belief system explains. Painting and photography can describe in a way. Science requires a definition that makes it distinct from either religion or art, and this is sufficient for the conclusion that the philosophical argument is poorly formed. Each alternative is a blind path. Myths and parables explain. The turtle holding up the earth explains what's beneath us. Creationism and religions explain how man got here and, moreover, why! Phrenology and astrology explain personality. OPEC agreements on oil prices hold the explanation for stock market movements.

None of these explanations is science. Why? What is there in the understanding of what science is that is missing in its definition? The definition of science, embodied in its objectives, must qualify science as a fundamentally different undertaking.

Photographing and sketching, classifying and cataloging, whether of objects or processes, are an important part of the story of science, but only as a link in a much larger chain. Neither description nor explanation provides understanding, nor much intellectual satisfaction of man's curiosity. The Strategy does not ask Science to explain, but through its predictive power point to possible Cause & Effect relationships. Science relies on its models to predict novel facts, assuming the Cause & Effect Principle as an axiom.

AXIOMS

For the first step in the defining process, the Strategy forms a set of axioms for the evolution of the meaning of science. These basic assumptions define the boundaries of a particular Real World, the Real World of discourse but not necessarily The Real World.

All assumptions, especially axioms which serve to fit man's thoughts to the Real World, should be candled like a fresh egg. The contention here is that man must challenge his physical world models. He begins by challenging his mathematical world axioms which are the links to the Real World. The Strategy makes this notion a defining part of scientific method. It includes challenging accepted vocabulary and logic. The entire process requires rationality, so the Strategy starts with an Axiom of Rationality.

0. Axiom of Rationality

Science and science teaching have no place for the irrational. Therefore the Strategy begins the axiomatization of science by summarily dismissing Feyerabend and any followers he may have with Axiom 0 (Roman numeral zero):

> Axiom 0: Rational Domain. The domain of discourse lies in rational thought.

This is not so much a description of the territory of science, but of the collective individuals involved in science. It transcends science; it is an assumed property of knowledge. A less trivial aspect of the Axiom of Rationality is that all who practice the art agree to define their terms, and when challenged to define them even better.

I. Axiom of Curiosity

As Axiom 0 characterizes knowledge among man, Axiom I specifies an important attribute of his species. This is a subjective notion related to the ideas that man has inherent needs to know, to influence or control, to understand, and to be more efficient.

> Axiom I: Axiom of Curiosity. Man must answer all questions; he craves reasons and knowledge of the future.

This is a presumption of the human spirit that drives man individually and collectively to learn and to predict. It does not necessarily separate man from other animals, but it is worth stating because it is the driving force behind Science.

II. Real World Axiom

The first nominee is the Real World Axiom.

Axiom II: Real World Axiom. There exists an all encompassing Real World beyond knowledge.

This just settles the issue. Since Science creates models of the Real World, by this axiom it cannot properly model itself and hence is denied the self-referencing attribute. The property of self-referencing in Science is reserved to this Strategy for Science Literacy! The Strategy leaves it to the philosophers to argue whether or not the Real World Axiom is a proper axiom, whether or not it is actually a theorem, and whether or not the Real World is unique.

> For in and out, above, about, below,
> 'Tis nothing but a Magic Shadow-show
> Play'd in a Box whose Candle is the sun,
> Round which we Phantom Figures come and go.
> Omar (F52, XLVI, p. 64)

The objective here is to put aside the entertaining mental gymnastics and to get on with the business of science.

III. Cause & Effect Axiom

The next nominee is Cause & Effect, an attribute of the Real World. If a scientist is a theist, he might say about Cause & Effect that God has set the stage, leaving His message for us in nature.

> The Moving Finger writes; and, having writ,
> Moves on: ...
> Omar (F52, L VI, p. 117)

Science, to the theist, might be an apostle's errand! However, science itself is neutral on the subject of ultimate cause, even for the scientist who is a Believer.

Axiom III: Cause & Effect. Each Effect observed in the Real World has a discoverable Cause in the Real World.

This is similar to closure in mathematics, but the Strategy will reserve the word closure for a different sense.

IV. Axiom of Measurements

Could an observation in Cause & Effect be objective but unmeasurable? The Strategy might allow that such pathological situations exist, then simply work with the residue, the smaller set of measurable things. This would lead to an operative definition of Science. Instead, the Strategy assumes the Axiom of Objective Observations, which incorporates the definition of measurement.

Axiom IV: Measurability. Every objective observation is comparable to an unambiguous standard.

Comparing with a standard is by definition measuring. Consequently, all objective observations are measurable. If a field of discourse exists containing well-defined objects, then the definitions must make these objects mutually differentiable. Discrete decisions about whether or not a specimen possesses some attribute or not will lead to an objective decision about the name of the object. Measurements in such a case involve language, but may not yield to quantifying or ordering.

V. Axiom of Randomness

The next candidate for the axioms of science says that there is no such thing as a perfect measurement. Scientists can't even be sure that they counted to one accurately!

Axiom V: Uncertainty. Every measurement has an error.

Every measurement has an ultimate inaccuracy which must be assessed. If the inaccuracy is not in the quantifying, then it is in the definition of the thing measured.

Philosophers argue about randomness. Entropy, the measure of disorder, is a universal property in the Real World. Yet another school holds with the idea that randomness measures man's ignorance — what is unknown. Perhaps Einstein was saying that he was of the latter school when he said, "I shall never believe that God plays dice with the world." The latter view not only suits Science, but provides an endless source of research. Science must hold as well that uncertainty always exists in its models, never satisfied with the level of understanding.

In fact, Science holds with both contradictory views simultaneously. How can this be? Entropy is a brilliant concept in thermodynamics, a part of all Science. Is thermodynamics, then, part of epistemology, the study of what is knowable?

VI. Master Clock Axiom

The next axiom was a topic in the introduction:

Axiom VI: Master Clock. There exists a master clock which is universal, uniform, and unidirectional.

Scientists may not actually need this axiom, but it keeps them from spending too much time on scientific or philosophical tangents. For the convenience of practicing scientists, it denies the Twin Paradox of relativity. This may be like the mathematical Axiom of Choice. Note that if the Master Clock is non-uniform, the effect would not be determinable. Science might need a similar set of axioms for space as well, and the two might constitute the axiomatic existence of an inertial reference frame.

VII. Axiom of Least Work

Next is a concept from evolution and adaptation with strong parallels in physics and economics.

Axiom VII: Axiom of Least Work. Systems that can adapt will evolve to the least expenditure of energy.

Perhaps this is a corollary of a thermodynamic law and the law of increasing entropy; it is a relative of maximum uncertainty, as in uniform probability densities. Life and many natural processes sluff excess baggage, seeking ever more efficient forms just to survive. A corollary to the axiom argues that absent external influences, a system will become less and less robust. This axiom is fundamental to a theory presented in the epilog to this Strategy for evolution and adaptation.

VIII. Axioms and Rules of Logic

The next axiom is actually a set of axioms, placed last because it is too non-standard and long to enumerate usefully. These are the axioms of logic, which appear in different forms under different authors.

Axiom VIII: The Axioms and Rules of Logic.

Man comes with certain tools, including language with its imbedded logic! Logicians have extracted certain axioms of logic and proof from the languages. Controversy continues today about which notions are fundamental and necessary. These axioms, in one version, would begin with the elementary methods of proof, as in Modus Ponens (method of putting) and Modus Tollens (method of taking).

Kalish & Montague, K64, give their popular structure to logic, summarized in the table on the right with some well-known theorems. In other structures, the theorems may be axioms, in which case the Kalish & Montague assumptions will become theorems.

WHAT IS SCIENCE?

The Strategy strives to circumvent all teaching that science is a thing in and unto itself, an isolated foreign territory. Science is inseparable from man and knowledge. Its domain has no boundaries. It serves man by accounting for the natural or Real World.

Knowledge

The defining process begins by declaring that science is the objective branch of knowledge — more particularly, of man's knowledge.

1. Science is a branch of knowledge.

Science is fare for human consumption. Therefore, it must make the connection to the subjective world somewhere in its workings. Does it seek truth, and what does truth mean?

DEFINITIONS	NOTIONS
Negation	Arguments
Conditional	Fallacies
Conjunction (*AND*)	Truth value
Disjunction (*OR*)	Tautology
Equivalence (*IF & ONLY IF*)	Sentences
Universal Quantifier	Predicates (variables)
(*FOR ALL*)	Bound and free variables
Existential Quantifier	Universal Instantiation (UI)
(*FOR SOME* or	Existential Generalization (EG)
THERE EXISTS A)	Existential Instantiation (IE)
Descriptive Operator (*THE*)	Universal generalization

INFERENCE RULES	DERIVATIONS
Modus Ponens (MP)	Direct
Modus Tollens (MT)	Conditional
Double Negation (DN)	Indirect (reductio ad absurdum)
Repetition (R)	
Simplification (S)	Universal derivation
Adjunction (Adj)	
Addition (Add)	
Modus Tollendo Ponens (MTP)	
Biconditional-Conditional (BC)	
Conditional-Biconditional (CB)	

SOME IMPORTANT THEOREMS			
1.	Syllogism	12.	Composition principles
2.	Distribution Principles	13.	Separation of Cases (SC)
3.	Commutation Principles	14.	Conditional-Disjunction (CD)
4.	Double negation laws	15.	Law of Excluded Middle
5.	Transposition Principles	16.	De Morgan's Laws
6.	Association Principles	17.	Quantifier Negation (QN)
7.	Exportation	18.	Confinement laws
8.	Factoring principles	19.	Vacuous Quantification laws
9.	Dilemma principles	20.	Alphabetic Variance laws
10.	Contradiction Law	21.	Aristotelian syllogism
11.	Laws of Indempotence for *AND* & *OR*	22.	Russell's Paradox

STRUCTURE OF LOGIC
Table 4-1

In logic, truth is nothing more than an arbitrary two level value assignment to symbolic sentences. This truth assignment propagates through other sentences according to prescribed rules. So logical truth is black or white. On the other hand, if a sentence refers to a statement about the Real World, truth is by degrees — contextual or situational.

To say that cows have four legs is a true statement. However, it is a true statement more about the attributes of the word *cow* than it is about Real World bovines. There may well be a cow in a side show somewhere with five or six legs! The technical or logical implication of the original statement is that ALL cows are quadrupeds.

Or suppose some farmer's cow lost a leg falling into an old well, but managed to survive to this day on three legs! To make matters worse, we can't know that such a poor creature doesn't exist somewhere. Only in theoretical terms could we know it to be. People can't even count the citizens of China or the homeless in Atlanta, let alone take a census of all the world's bovine creatures. We are on the fringes of what is knowable here, a sort of pragmatic epistemology.

Objectivity

Science is the largest and fastest growing body of mankind's knowledge. Its domain is the Real World, including both the natural world, and the world of man-made objects and processes. The natural world contrasts specifically with the supernatural world, if any.

A *supernatural object* or *process* is one that is unmeasurable.

A *process* is a transfer of matter, energy, or information in time or space.

Technology is the branch of science that deals with the man-made world.

Basic science operates on the objects and to an even greater extent the processes of the natural world. Where no confusion is likely to arise, the word science replaces basic science.

Measuring, the grading of observations according to standards, and precision in language are processes necessary to achieve objectivity. Objectivity is the separation of observations from the perception processes in man. So the Strategy declares that

2. Science is the objective branch of knowledge.

Science deals with observations that man can define, record, measure, and quantify or order. *Record* means to capture data in a physical medium that is amenable to measurements, not simply notes of an observer.

Scientists should practice objective communications beyond their own field, and even beyond the set of all scientists! Scientists are custodians of their knowledge for all mankind, duty-bound to share it with the public at large. They need to strip their knowledge of its vernacular or jargon, presenting it in terms understandable to a high school graduate. Meanwhile, science educators need to prepare a literate public by expanding their objective thinking, opening them to this critical knowledge.

Man naturally expects his science to provide that subjective satisfaction that understanding can give. Science provides man a strong sense of things explained and described. However, no matter how convincing these explanations might be, they remain subjective values. They are outside of science, the collection of objective arts. The definition restricts Science to the objective world. Science does not have within its scope the ability to attain any subjective goal. This might mean that the definition denies science the ability to be self-referential!

Shared, Public Knowledge

Science is man's servant and must have as its goal the service of man. This is the beginning of a mandate for sharing in science. It must be public knowledge, not private. As important as the mission to serve man is the requirement to be objective.

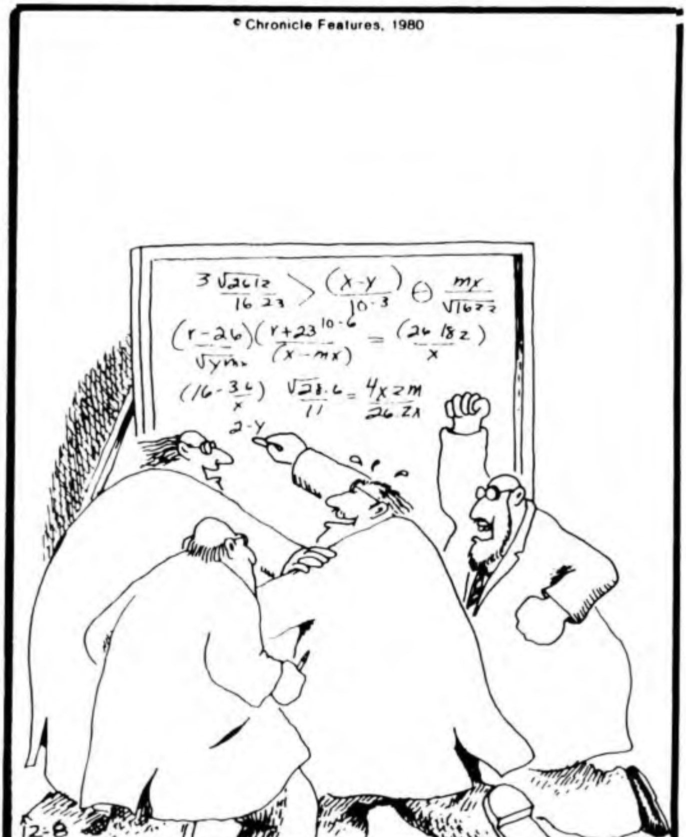
Objectivity is certain only through communication among individuals. The Strategy cannot require that individuals be dispassionate and unbiased, for such people are too rare and impossible to certify. Instead, the Strategy invites individuals of all passions and all biases to a communion where they can challenge each scientific declaration. The only prerequisite is to behave rationally.

Objectivity exists only by sharing. An individual scientist may think himself objective, and indeed he may be in some regards and some better than others. A reporter might receive honors for objective reporting. Still, no one can never be sure without critical feedback. Even a small group can easily fool itself into thinking that it has a grasp on a new truth when in fact it is in error. Sharing over the larger audience invites all prejudices to participate.

Science allows man to communicate coherently, and thus to share experiences! Coherence means that when we add concepts, the pattern part will reinforce and the noise part will cancel itself in some absolute or relative sense. Hidden in here is the germ of the meaning of *signal to noise ratio*. Science by its method brings many senses together on a subject — thousands of eyes, ears, and other senses. And more! Science allows man to assemble senses from times beyond our lives and to places where no man has ever been, creating an even larger coherent image. Science is an array of knowledge where the whole is far greater than that held by an individual element.

3. Science is shared, public knowledge.

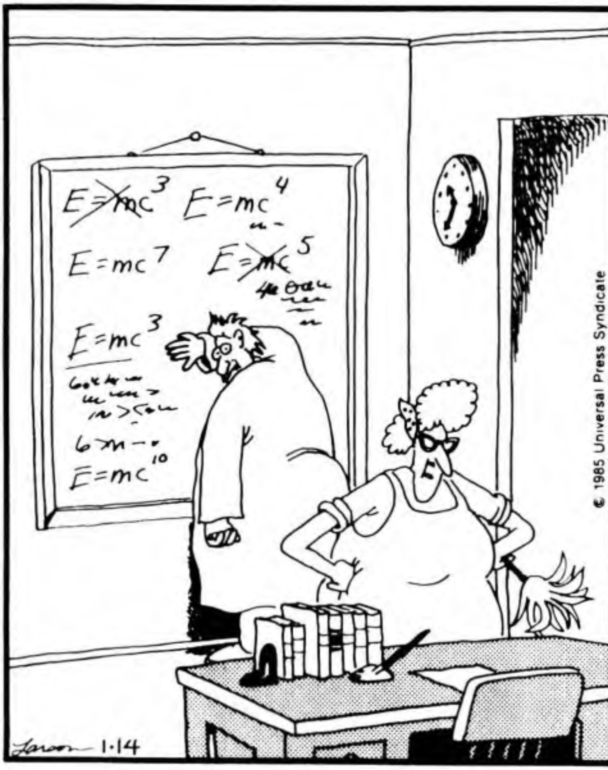
Science is a semi-open public process. Being public is an essential ingredient that mandates two-way communication between individuals. It causes us to insert language, logic, abstraction, public testing, and vocabulary into the process. Science is a semi-open process because of unavoidable human needs. Secrecy is more than the bureaucracy of government classification, and the trade secret protection of industry. It occurs in academe where publishing second is a mortal fear. As Gary Larson [L84] observed, the competition is fierce:



"Go for it, Sidney! You've got it! You've got it! Good hands! Don't choke!"

SCIENTIFIC COMPETITION BY LARSON
Figure 4-1

The superior astronomer is the one who gets to the telephone first to report the supernova! More important and more charitably, perhaps, is the human need for the freedom to think that privacy affords. Larson [L86] also shows why Einstein wanted his privacy:



"*Now* that desk looks better. Everything's squared away, yessir, squaaaaaared away."

SECRET SCIENTIFIC INSPIRATION BY LARSON
Figure 4-2

Between professional publications, scientists can be as wild and as subjective as any other human being. The media overflow with examples. Large, prestigious bodies of scientists can be wrong. When they abandon method and when they express unanimity, the odds increase that they are. The odds become astronomical when the body or its members can dip more deeply into the government coffers because of their recommendations.

A popular view among educators is that one should not use phrases like, "Most scientists believe ... ". This phrase may be inappropriate to Science, but it is perfectly acceptable applied to scientists. For example, most scientists believe in ethical conduct and social responsibility. Most scientists believe that professional recognition is important.

Scientists may have beliefs, but not Science. Scientists have favored theories — which procedure is likely to work (that is, to produce the desired result and to gain peer approval), which theory is likely to receive reinforcement, modification, or fusion in a larger body of theory. Science has principles, conjectures and hypotheses, but not beliefs. Science does not accept concepts as true. Instead, science challenges its own most cherished foundations. Each discovery, each new theory, each new crack in certainty, is a commandment to reexamine the footings.

Science takes nothing on faith, not even its own principles. "If the principle of Cause & Effect holds, then ... " or "If the logic of Whitehead and Russell holds, then ... " are safe hypotheses for appending to any scientific statement (that doesn't deal specifically with Cause & Effect or logic).

Objectivity is not an absolute, and it is not guaranteed simply by supplying measurements. Objectivity lies in scientific models and their predictive powers. Objectivity is not a discrete entity, present or not, but is a continuously valued parameter.

Even when everyone agrees to a truth, science begins to doubt. Not only does the process need the breadth of shared knowledge, but to advance it must continuously challenge and retest what will become, in the end, subjective beliefs of individuals. Often the new thrust of progress comes like a bursting of a dam of the obvious and the accepted. What is universally held is suspicious, especially when it is a tacit part of the assumptions.

An excellent example is the recent confirmation that the defective human gene that causes myotonic dystrophy will grow from generation to generation. Previously, epidemiologists had observed that the disease process would worsen each generation, leading from perhaps nothing worse than cataracts in old age to finally manifesting itself in terminal muscular dystrophy in young children. Other diseases were suspected of following a similar epidemiology. This possibility was dismissed as apocryphal or statistically insignificant by geneticists because it was inconsistent with the accepted model for inheritance. In this model, genes might randomly mutate but that event was highly improbable and equally aimless. Much more likely, a gene would be passed unperturbed in reproduction, or with the same odds not passed at all. Instead, this gene not only changes during reproduction, but in a known direction. The gene has a parasitic life cycle of its own! This result modifies but does not overturn Mendelian Laws of Inheritance. The discovery casts the Mendelian theory in the context of a larger, more encompassing model.

Because of subjectivity in private experiences, science makes experiences objective. This is not a psychological need to share, but a capacity limit each has to information and models. Man's knowledge base is much, much too large for one person to handle. Sharing beauty or religious experiences might enhance their value. Sharing these things might give support in the correctness of one's views, much as finding oneself in the majority on a political poll. However, people don't *need* to share beauty or religious experiences. Sharing these is not essential; people can collectively enjoy these experiences absent even vaguely similar perceptions. Not so in science!

Models

We can sit together on the cliffs and share the sunset. We can experience it together, but this does not account for it. We can dream a thousand dreams that account for the motion of the sun and its sinking into the sea every evening. We can paint pictures of the sunset or build physical descriptions of the phenomena. As Dr. David Viscott [V72] says

> Even if he may not express in words what he knows, the artist seems more in touch with the real world and the world of his own feelings than do others. The artist brings the world of reality and the world of feelings very close together. The artist also lives in an illusion, but he takes his illusion and gives it form and makes it real enough so that others can share it. In so doing the artist tries to make sense of his own life. By sharing what he has created with others he allows them to expand and enrich their illusion and perhaps gives sense to life itself.

We call each of these concepts, these accountings, *models* of the Real World whether or not they intentionally reflect the observer's feelings. Why do such models fail to have currency in science? Today, we can telephone a friend on another continent or better yet, call an astronaut on the radio. Ask him what he sees from his vantage point about our sunset. His experience is so vastly different that he cannot share in any of our explanations that we now see as mythological.

> 4. Science creates models that account for observations of the Real World.

Are there truths in nature which science can model? Are there unique laws and unifying concepts for science to uncover? Is the answer that scientists seek somehow predetermined in a correct form?

Suppose some scientific model was an accurate and complete model of a Real World phenomena. Would conclusions reached by proper induction on that model be as fitting to the Real World? These problems are the core of the differences that divide various schools of philosophy. Science can't know these answers, and so this discourse is by definition outside the domain of science. It remains in philosophy.

While man's ability to measure improves continuously, all measurements have a residual error. So even though scientific models improve, each model has a limitation in accuracy. Science along with its companions of mathematics and logic all rest on assumptions about the Real World, which reside in models.

If the argument were not enough that each model has limits, consider that models evolve and in most cases science simultaneously holds with more than one model. Examples include Newtonian and relativistic models for mechanics; the duality of electromagnetic energy as particles and as waves; competing cosmology theories of steady state and Big Bang, with or without the Cold Dark Matter Theory. Gary Larson [L84] got here first again (see next page).

Evolution vs. Creationism is a non-example because, as will be shown, Creationism cannot qualify as science. Creation Science is an oxymoron, invented for political purposes, both as a futile attempt to make Creationism qualify as science and in the mistaken belief that science admits belief systems.

Scale. Scientists deal with simultaneous models everyday, perhaps working with some collection of

physical mock-ups,
word descriptions,
abstract models in equation form,
equations in the time & frequency domains,
linear & non-linear models, and
computer simulations and emulations of various
classes, as in deterministic or Monte Carlo.

Scientists deal with models at various scales. *Scale* can refer to the size of the objects under study, as the range of systems from galaxies to atoms, the range of life from microbiology to mammals, or the range of bodies from planets to quarks. *Scale* has a deeper philosophical meaning in Science, one that if appreciated elevates it to an important theme. This is its reference to study of a process with different sets of parameters that represent different levels of *resolution*.

"There goes Williams again . . . trying to win support for his Little Bang theory."

COMPETING SCIENTIFIC MODELS BY LARSON
Figure 4-3

Scientists can study climate with the coarse resolution of the global view, with the middle resolution of national weather, or with the finest resolution of microclimates defined within six feet of the surface. Similarly, biologists study evolution at the macroscopic level in population models and simultaneously at the microscopic level in cellular models.

Closure. A major task of scientists is to make their various models agree, creating *closure*. In basic science, the creator of a model strives to bring his model into agreement with experiments. An analogous situation holds in technology, except that technology uses a minimum of two models. One of these is a physical model that serves in the place of the natural world of basic science. The objective of the engineer is to obtain satisfactory closure between the physical model and his theoretical description. The process technologists call engineering development.

Closure is also a prized objective of basic science when models of different scale are brought into agreement. One of Stephen Hawking's more important contributions will be the modeling of Black Holes, the most massive objects in science, in terms of quantum mechanics, previously applied only to the least massive objects known. This is not too surprising since the Black Hole enjoys the mass properties of a gargantuan star compressed to the atomic scale.

Facts. Each model of a Real World phenomenon must be consistent for all observers. Indeed, this is the philosophical underpinnings of Einstein's theories of relativity. From consistency comes the requirement for *measurements*. A measurement is a comparison of observations with standards, creating what science calls *facts*. In this definition, the terms *measurements* and *facts* become interchangeable. They are what scientists and philosophers call *à posteriori*, meaning "after the fact" or "from experience". Making measurements, showing consistency, and sharing results are all scientific processes that assure objectivity. Science thus becomes the objective branch of man's knowledge.

5. Scientific models build on measurements of the observations.

This definition separates the domain of science from subjective experiences. With this distinction, much of what passes as classical philosophical Empiricism fits with modern science.

Principles. Scientific models invoke *principles* as well as facts. Examples of principles include

Cause & Effect
the Principle of Least Action or Work
Fermat's Principle of Least Time
the Principle of Relativity
the Equipartition Principle of Energy[1]
the Least Energy Principle
Maximum Efficiency
Laws of Conservation and the closely related concepts of Symmetry in physics
Descent with Modification
Uniformitarianism
and perhaps the Laws of Thermodynamics.

A principle may be an axiom, an idea drawn from reasoning, or factor simply presumed for the scientific discourse. A principle which is also one of the Strategy's axioms is Cause & Effect. It appears as an axiom because its use is universal and always tacit. The Axiom of Least Work is almost as universal as Cause & Effect, but scientists do not appeal to it as readily without identifying it.

Any idea drawn from reasoning scientists and philosophers call *à priori*. The principles of maximum efficiency and least work are examples. Presumptions include ideas like Uniformitarianism, which geologists and astrophysicists apply because it makes the analysis of their facts tractable and fruitful.

Principles remain valid and useful so long as they are consistent with the facts. This kind of support by facts makes principles similar to generalizations. A principle in particular is not amenable to modeling and validation, for if it were,

1Energy in a system in equilibrium will be equally distributed between among all the degrees of freedom.

scientists would cast the principle as a theory, placing it on the track to becoming a law. Like models themselves, principles are creations of man and may not be unique.

Generalization. How can science assure that a model of some phenomenon is not just some more elaborate mythology that accounts for a wider variety of observations? If the goal of modeling is simply explanatory, it leads to little more than logical generalization.

Still, generalizations make feasible and frequently useful models. A model that does no more than a previous model but does its work more efficiently, that is, with fewer assumptions, is a valued addition to the scientific repertoire. This new model inherits the character of its parent model; if the parent was a generalization, so is the child.

No scientist could prove a generalization unless and until all possible observations had occurred. Note first that once all the possible observations have occurred, no model is necessary. No prediction is required, for everything is reduced to fact! Until that happens, repeated testing reduces the error in the generalization in a mathematically accountable way. However, if the phenomena can occur an infinite number of times, perfect confirmation is impossible. This has been a major problem for philosophers of science. It is the origin of Popper's Falsification Principle. It leads to a demand for more from scientific models.

Prediction. The general solution to this problem put forward by this Strategy is that each scientific model be able to predict fresh objective observations. It requires observations qualitatively different from those used in the construction of the model. A qualitatively different observation implies different parameters or different boundary conditions than those that formed the model. It doesn't just increase the probability that the generalization is correct. Qualitatively different observations might take the form of a new phenomenon never before observed. The shifting of starlight around the sun, or the particle behavior of light are historical examples.

A more common type of qualitatively different observations would be the relationship between a pattern and a controlling parameter in a way not previously expected. The discovery of cross-over in meiosis may be an example of this second type. It showed that Mendelian inheritance had a finer structure and many more possibilities than arise from the simple pairing of chromosomes.

A third form of qualitatively different observations is a unifying model. This is a model which shows the equivalence of different phenomena. The unification of light and electromagnetic energy is an example of this last type.

Science looks for a new Effect produced from a novel Cause & Effect relationship, or a new Cause for a known Effect. Note, however, that science neither seeks nor claims an ultimate Cause. Scientists today are looking for an improvement to the General Theory of Relativity, one that will better account for gravity. Others will surely be looking for ways to predict and control cross-over in reproduction. The quest is endless.

When a model produces a qualitatively different prediction which scientists might actually confirm, then the model is falsifiable in Popper's sense. When a model does nothing more than express its founding facts, it is a generalization. Even if such a model should be correct and accurate, scientists can never validate it fully. A student might measure the arrival of trains at the depot, and conclude that all trains arrive on time, or the converse.

Validation. For a model to be falsifiable in Popper's sense, it must produce predictions and it must be testable. The creator of the model need not test it, but he must design a model that eventually could be subjected to a novel experiment.

Of course, a generalization is falsifiable. The task is done as soon as an experiment produces the first counter-example. Until the falsification occurs, though, the process of confirming simply adds to the data base of facts that supported the original model. Each new fact mathematically changes the accuracy of the measurements and hence of the model. This is a weak, statistical process. It limits models of generalization to a form of second class citizenship among scientific models.

When the prediction introduces a novel Cause & Effect relationship, a confirming experiment introduces a degree of validation. This is confirmation, but of a prediction. The model, not yet certain and destined never to be certain, is stronger. Facts exists where previously there were none.

6. Scientific models require validation through confirmation of predictions of qualitatively new phenomena or relationships.

The Strategy has thus derived the most fundamental requirement that science be able to predict. Prediction requires a practical or feasible experiment, but does not require a controlled experiment. Many scientifically valuable experiments are imaginable which would be unethical, impractical, politically unacceptable, or simply beyond the state-of-the-art. Ethics and laws prohibit certain genetic or social experiments on humans. A full scale emergency evacuation test of a city to validate a computer traffic model is both impractical and politically unacceptable. Most experiments that might validate economic models are accessible to politicians.

Nothing in this derived definition of science implies a time sequencing of events in science. Later, when the Strategy talks about the scientific method, this idea of time sequence as opposed to logical ordering will arise again. Data, on measurements, may come before or after the model or any part of it.

In every scientific endeavor, there is an abundance of procedures — methods to achieve an objective. There are local differences between laboratories, companies, and universities, all within a common field. Standardization of method helps achieve repeatability and corroboration. It saves time in inventing a method and later in communicating what was done.

Scientific methods come in various scales, much like models themselves. At the coarsest scale, common methodologies include such procedures as

double blind testing
controlled experiments
accelerated testing
randomized sampling
independent testing
prediction before experimentation
concurrent theoretical and practical modeling
concurrent computer modeling, and
mathematical modeling.

At finer scales, procedures are specific as to operations like the order of processing, curing or other action times, tolerances, cleaning, and so on. At each scale, these highly valued techniques are always provisional in nature, and scientists should subject them to reevaluation and experimentation.

Observations frequently follow the model, as when a scientist extrapolates a model to a new domain. It can happen when scientists attempt to replicate results of others. Astronomers predicted the existence of the planets Neptune and Pluto from Newton's theories before astronomers observed them. Einstein predicted a previously unobserved shift in the path of star light as it passed large gravitational bodies. Astronomers had to wait for the next total eclipse of the sun to observe the phenomenon. Some predictions concern future events and some simply future measurements.

The Definition of Science

In summary, using classic strategic planning concepts of mission, goals, and objectives,

Science is the objective branch of man's knowledge.
* *Mission*: To serve man by accounting for the Real World in a constructive way.
* *Goal*: To create useful models of Real World phenomena consistently based on measurements.
* *Objective*: To predict novel phenomena or relationships that validate the models.

Later, the Strategy will expand on this definition to include Technology, a branch of science that extends the scientific mission, goal, and objectives to the man-made world.

Does science explain the Real World? Whether or not it does, each will decide for himself. Mankind determines the value of science, and so its performance rating is, in the end, subjective.

HAWKING ON SCIENCE

Stephen W. Hawking in his recent book, *A Brief History of Time* (H88) provides authority for many of the Strategy's ideas. There is substantial agreement between the two views, with two minor exceptions. The first difference concerns a certain physics-oriented view. The second deals with the scope of models, as discussed below under Degrees of Freedom. Hawking would not likely find fault with either criticism.

Now Hawking, writing for the layman, may be speaking of physics, not science, when he says, "The eventual goal of science is to provide a single theory that describes the whole universe." The Strategy takes exception in the literal sense. It can't require of science that within the next century it link, say, the organization of the human genome with the elusive unified theory of relativity and quantum physics. There may be a touch of Lord Rutherford's arrogance in Hawking's goal for science, for it was Rutherford who said, "All science is physics — the rest is stamp collecting."

Predictive Models

Nonetheless, Hawking's ideas generalize neatly to all science. Many of the philosophical ideas contained in the Strategy lie in this excerpt:

> In order to talk about the nature of the universe and to discuss questions such as whether it has a beginning or an end, you have to be clear about what a scientific theory is. I shall take the simple-minded view that a theory is just a model of the universe, or a restricted part of it, and a set of rules that relate quantities in the model to observations that we make. It exists only in our minds and does not have any other reality (whatever that might mean). A theory is a good theory if it satisfies two requirements: It must accurately describe a large class of observations on the basis of a model that contains only a few arbitrary elements, and it must make definite predictions about the results of future observations. (H88-p. 9)

Taking Hawking's last point first, the Strategy agrees that on a relative basis a model must contain fewer elements than the number of observations it fits. Even if the model is only marginally smaller than the number of observations, scientists develop confidence through future observations properly predicted. Science also gives considerably more weight to a validation than to a datum included in the development of the model.

One infers from Hawking that the better model will use fewer arbitrary elements to predict to the same accuracy. Science applauds the inventor of the elegant model, but science does not demand that models always contain few independent factors.

In the paragraph cited above, Hawking is explicitly introducing the notion of models. When he says "to talk about" and "to discuss" the natural world, he is requiring the sharing of knowledge. He obliges science to account for the Real World by specifying the rules that link the models to our observations. And lastly, he requires that the theory, as expressed solely by the model, be able to predict future observations.

Note how carefully Hawking has chosen his words. He uses precision in his language so that his audience might share his ideas unambiguously and then build upon them. He specifies not that the model predict future events, but future observations. This is especially true in sciences like anthropology and cosmology, where for remarkably different reasons, future observations are made about past events.

Degrees of Freedom

Hawking's requirement that a model "describe a large class of observations" with "only a few arbitrary elements" needs elaboration. This is a complex issue, involving what scientists, engineers, and mathematicians refer to technically as *degrees of freedom*.

The idea seems clear intuitively that an arbitrary element in a model is a degree of freedom. Here's how it works. If a scientist were to model the price of a stock, he would most probably begin with the last closing price. That would be his first degree of freedom. From this single datum or fact, he can make what a *zeroth order* prediction. This is, "Tomorrow's price will be the same as today's!" As it turns out, this is about the state-of-the-art in popular market forecasting!

Even the novice would add the previous day's price to the model as the second degree of freedom. Now the experimenter can make a *first order* prediction. He has two data points, and he might combine them to say, "Tomorrow's price will change from today's price as much as today's price changed from yesterday's." This first order prediction turns out to be worse than the zeroth order prediction, so he continues.

A sophisticated scientist conceivably could add the stock volume, that is, the number of shares traded yesterday, as his third degree of freedom. He could continue to expand his model by including the latest Company earnings, yesterday's stock market averages, the industrial sector averages for his stock, and the latest data on inflation and interest rates. If each element is a single, independent data point, he now has accumulated eight degrees of freedom.

He could continue indefinitely, adding the price of oil, energy prices, seasonal adjustments, or anything else quantifiable. Each parameter opens new opportunities for added degrees of freedom. Each new datum adds a degree of freedom to his model with one proviso, it must be *independent* of the all other data. Independence means that none of the elements is a simple combination of some of the other elements. (There are mathematical ways to test for this independence.)

Now the stock market scientist discovers that he can make his eight degree model match any sequence of eight stock prices exactly! Unfortunately, this seeming perfection is not a property of his scientific model! The scientist has not discovered through insight or luck a set of elements with predictive power. A stock market model with eight degrees of freedom is guaranteed to fit the weights of the next eight people to come into the room, in any order. It can also fit slightly longer sequences of numbers quite closely, depending on how the scientists and investors agree to measure closeness. With eight wins, a loss or two is acceptable.

Each independent measurement or observation that the model must match consumes a degree of freedom. A model has little value unless it has many fewer degrees of freedom than the observations that it fits. If our scientist creates a model based on too few observations, he is likely wasting everyone's time. To make his model efficient, he should build it upon a number of observations that is many times the number of degrees of freedom. Then, it must survive the test of predicting future observations. Just matching a sequence of prices, for example, is an extremely weak test.

Certainty

Hawking says,

> Any physical theory is always provisional, in the sense that it is only a hypothesis: you can never prove it. No

> matter how many times the results of experiments agree with some theory, you can never be sure that the next time the result will not contradict the theory. On the other hand, you can disprove a theory by finding a single observation that disagrees with the predictions of the theory. As philosopher of science Karl Popper has emphasized, a good theory is characterized by the fact that it makes a number of predictions that could in principle be disproved or falsified by observation. Each time new experiments are observed to agree with the predictions the theory survives, and our confidence in it is increased; but if ever a new observation is found to disagree, we have to abandon or modify the theory. (H88-p. 10)

Proof is for theorems. The practice of science proves models valuable, more than the Method proves them in any absolute sense. Scientists become more comfortable with them as they become more reliable. Still scientists must always be alert for changing conditions. The data can never be complete, and need not be so. This is no bar to the validity of the scientific process in any way.

Elegance

The Strategy discussed degrees of freedom above in a relative sense, focusing on the excess degrees of freedom. It compared the number of arbitrary elements in the model, to use Hawking's words, to the number of observations. Hawking says that a good theory must contain only a few arbitrary elements, where he might mean few in an absolute sense. If so, then Hawking is introducing elegance into the method. A theory like Newton's gravitational formula, with only three variables that can account for unlimited quantities of orbital data, is indeed elegant.

Perhaps the finest complement one can bestow on a scientist is that his theory is elegant. Complex formulas based on statistical correlations are stingy with the insight they provide into nature, even though they may fit nature quite well. Scientists test each model asking whether or not nature obeys a simpler, more elegant formula, and they seek such a relationship. These models are man's creations. As Albert Einstein said,

> Physical concepts are free creations of the human mind, and are not, however it may seem, uniquely determined by the external world.

Still, science is not weaker because nature fails to reveal such elegance to a scientist somewhere. To explain economically is a highly valued concept, but not without dangers. Scientists must be alert to problems with scale. In the search for elegance, they may have approximated away natural complexity. They may be suffering from observing the natural world too coarsely.

Experimenters can usually increase the resolution of their measurements, placing greater demands on the accuracy of the resulting models. Similarly, scientists must be alert to the loss of independence that occurs should they make measurements too finely in time or space.

RANDOMNESS

Science has no room for determinism. Science is that branch of knowledge that deals with uncertainty, specifically by making predictions. Determinism replaces uncertainty and predictions. Scientists take some comfort when their models differ from nature by random errors. They perpetually search the data, looking for order in the errors between models and observations. When a scientist finds order, known also as pattern, he adds elements to his model to account for the newly discovered differences. These differences he calls *systemic*.

Science may accept on faith that elements of a pattern reflect a common cause. This is the operation of the Cause & Effect Principle. When a pattern appears, scientists seek to extract a simple, single explanation for the repetition. Having found this economic Explanation, they find their faith reinforced that indeed they have found a cause.

The appearance of randomness can be quite deceptive. Having found that the error between the model and measurements satisfies all tests for randomness guarantees nothing. Several writers have remarked on the seeming randomness of the digits in a *transcendental number*[2], even though the number may have an obvious pattern as an infinite series or as a continued fraction. For example, consider π, the Greek letter spelled pi in English, which is the ratio of the circumference of a circle to its diameter. The Gregory-Leibniz series for $\pi/4$ intrigued many mathematicians and scientists:

$$\frac{\pi}{4} = 1 - \frac{1}{3} + \frac{1}{5} - \frac{1}{7} + \frac{1}{9} - \ldots$$

This means that the transcendental number π may be written as follows:

$$\pi = 4 * (1 - \frac{1}{3} + \frac{1}{5} - \frac{1}{7} + \frac{1}{9} - \ldots)$$

The pattern is plain to all. Yet the decimal digits in the expansion of the same number reveal no pattern. Out to the first zero they are

$$\pi = 3.14159\ 26535\ 89793\ 23846\ 26433\ 83279\ 50\ \ldots$$

All mathematical tests on the string of digits in π detect nothing but randomness. Indeed, theorems in mathematics say that because π is a transcendental number, the digits can have none of the obvious patterns of the geometric or algebraic type. Yet, here is but one example of chaos from a pattern. Scientists can take no comfort from the fact that a model differs from nature by random errors. A simple change of coordinates may reveal a pattern!

Much of the work of Albert Einstein came from his insight into the dependence of physical laws on man-made coordinate systems. The laws are man's expressions of patterns in the

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[2]A transcendental number is a number which cannot be expressed algebraically with integer coefficients. Examples include the square root of 2, the base of natural logarithms, e, and the ratio of the circumference of a circle to its diameter, π.

Real World, and so should be free from any arbitrary, coordinate system which is also man-made. To set the laws free from the coordinate system, Einstein created both the Special Theory of Relativity and then the General Theory of Relativity.

MISSION, GOALS, AND OBJECTIVES FOR SCIENCE

Having defined Science and outlining generally what a strategy should contain, this Strategy for Science Literacy is ready to present a mission statement, goals, and objectives both for Science and for science education. The three part table below contains a summary of strategic proposed statements for the public dialogue.

The intent of the Strategy is to select statements that currently meet with standards in the practice of these arts. The ethical requirements are ambitious challenges, however. The public has justification for its discontent with the maintenance of ethical and professional standards. This problem occurs in about every field, including legislatures, public administration, police departments, physicians, industry, and schools. The people deserve an ethics program that lies somewhere between secretive, self-serving committees and the witch burnings that destroy professional morale and public confidence to boot.

Another area likely to raise controversy is the mission for science education, which the Strategy presents specifically to be anti-egalitarian. The mission does not ask the education system to assume that all children are equal in ability, nor to make them so upon graduation from public school. The mission is not to provide children with some kind of abstract equity. Instead, the mission asks science education to provide an opportunity to every child that stresses his best effort. The rest is up to the child and his parents. The Strategy deliberately sets no direct objective for increasing the retention rate of students in the system. It presumes instead that the strongest motivation to stay in school and to learn comes from gaining knowledge in the experience and the personal challenge of competition, which this strategy provides.

MISSION Authority & Responsibility	
SCIENCE	SCIENCE EDUCATION
(1) To serve Man by accounting for the Real World objectively and (2) To serve Man through technology.	To serve the nation by giving every child the opportunity to learn Science to his maximum individual capacity.
Man is the master, Science the slave.	The Nation is the master, science education the slave.

GOALS Idealized Ends	
SCIENCE	SCIENCE EDUCATION
(1) To account for Cause & Effect in the Real World, bridging the gap between objective and subjective understanding through models with predictive power, (2) To extend Man's productivity and comfort, and his power, reach, and control over his environment, and (3) To develop and practice the highest ethical standards in scientific pursuits.	(1) To maximize the individual's acquisition of state-of-the-art Science, (2) To teach habits of thinking objectively and critically, of dealing with uncertainty, and of being skeptical, (3) To train individuals to exploit technology, (4) To improve continuously the talent pool for training in science careers, and (5) To teach and practice the highest ethical standards and conduct in science education.

STRATEGIC STATEMENTS
FOR SCIENCE AND SCIENCE EDUCATION
Table 4-2 L

OBJECTIVES Measurable Ends and Methods	
SCIENCE	SCIENCE EDUCATION
(1) To apply the Scientific Method universally, validating ever more accurate models of the natural world, (2) To produce more effective technology, and (3) To demonstrate publicly the application of ethical standards to the practice.	(1) To teach the Scientific Method broadly in each discipline, stressing each student to achieve at his fastest rate, (2) To build upon natural scientific curiosity, improving continuously the performance of K-12 students in science testing, (3) To increase the success rate of Americans in advanced education and training programs, and (4) To demonstrate publicly the application of ethical standards in teaching.

STRATEGIC STATEMENTS
FOR SCIENCE AND SCIENCE EDUCATION (Cont.)
Table 4-2 R

CHAPTER FIVE
THE OBJECTIVE WORLD

WHAT IS OBJECTIVITY & WHERE IS IT FOUND?

Anyone and any philosophy can predict, or prophesy. Anyone can say, "Join me and know the future." Many find peace of mind as followers of such easy lures. Any philosophy can safely predict the eventual end of the world, for we'll never know the result. Science, by definition, is the unique field that predicts measurable events which come to pass when tested. Measurement, the comparison of an observable with a standard, is the essence of that objectivity.

Not everything observable is necessarily measurable, although the converse is true. This follows at least because of the definition of observable: everything measurable is observable. Often the challenge to a scientist is to find the objective scale by which he can move an observable out of the subjective world. A scientist can observe human emotions, like grief, but how can he measure it? To an animal or a human, a material object may have utility but is that value measurable? Science is a transformation from a domain of objective observations to a range of objective predictions. By Axiom IV, this is the domain of measurements to the range of measurements.

THE ART OF MEASUREMENTS

As framed by this Strategy, the field of measurements is a candidate for the primary theme of science. To varying degrees of sophistication, it is part of the curriculum for engineers, physicians, physicists, mathematicians, biologists, and many other professions. In the broadest sense, the field of measurements includes

language
technologies of calibration
physics of transducers
adoption of standards
engineering of signal processing
mathematics of probability theory
applied mathematics in design of experiments
arts of data reduction & presentation.

Signal processing includes magnification, amplification, and feedback principles[1].

Measuring instruments and technologies include

rulers	protractors
thermometers	bridges
thermocouples	pyrometers
optical microscopes	electron microscopes
optical & radio telescopes	galvanometers
chronometers	chromatographs
radars and sonars	computers

spectral analyzers & spectrometers
a vast menu of meters & oscilloscopes

Measurement theory is rich in engineering, physics, and mathematics. Each new principle discovered in physics instantly becomes a candidate for a new measuring technique. Sometimes the whole of science seems to be an interrelated, interconnected labyrinth of models and measurement technologies.

Measurements Strand in K-12

At higher levels of sophistication, the art of measurements is an enjoyable pursuit, rich in intellectual challenge. At the low end, measurement theory as taught at the college undergraduate level is hypnotic, a frighteningly numbing experience. Any subject is better left untaught than to receive this kind of treatment. This is especially true in elementary school or under compulsory education. The instructor must do much more than just breathe some life into the subject.

The whole of measurement theory is much more than needed for a strategy for science. Subjects as entertaining as the Gee Whiz demonstrations that promote the Discovery experience of science are readily accessible to teachers for the

[1]For the sophisticated reader, it ranges from simple techniques like gating and integration, to the esoteric fields of modulation, detection and estimation theory.

measurements part of the curriculum. Teachers can select from the ever popular subjects of prehistoric monsters, outer space, bugs, and robots. The plan is to make the students think, and then to make them active in performing and presenting measurements. These are the first steps in teaching scientific objectivity.

Turn field trips to natural history and technology museums into measurement trips. Measure exhibits. Use triangulation for inaccessible measurements. Measure the floor plan of the museum or exhibit rooms. Measure the results of experiments made on interactive displays. At every opportunity, have them convert subjective observations to the objective, called measurements or facts.

The pedagogical strategy promoted here is twofold: to build intuition before theory, and to take advantage of the various stages of intellectual development through enriched environments. Consider deferring quantitative grading in the early years for absolute technical performance, meaning performance against a standard or norm for the age. Instead, attempt to assess the growth achieved by the student during the period. Defer absolute assessment until students have passed through the particular development stage. Lastly, make the measurements and experiments come alive through the visual aids of graphs and charts, creating instant gratification for the effort. The rule is Measure-See.

The basics to exploit mental development and intuitive foundations include

1. Defining objects for measurement; learning precision in language, learning root structures in English.
2. Logic structure inherent in language.
3. Algebraic abstractions of objects and concepts, not numbers.
4. Parameters, values, dimensions, units; conversions.

5. Making measurements; reading and interpolating scales; comparing to standards; measurement errors, accuracy, uncertainty, and resolution; recording results.
6. Graphical abstractions, charting results; position; rates; elementary models including interpolation and extrapolation.
7. Mathematics, including meaning of addition & multiplication, integers, fractions, decimals.
8. Non-deterministic thinking, including probability, probability densities, probability distributions, signal to noise ratio, coherence.

The Strategy requires equipping classrooms from kindergarten on as elementary, homemade physics and biology laboratories. The Strategy leaves to professional educators and teachers the job of placing these ideas at the appropriate grade level, but in a way guaranteed to stretch the children's abilities.

EXERCISES

The remainder of this chapter presents an assortment of familiarizing exercises. The demonstrations support the following few fundamentals of the scientific method:

(1)	communicate & observe	by specifying the measurement to be made
(2)	compare & communicate	by making measurements & recording them
(3)	order, organize, categorize, & communicate	by presenting the measurements in tables & charts

Again, the strategy is twofold:

(1) to train by providing a familiar background that will serve as a reference for theory, and

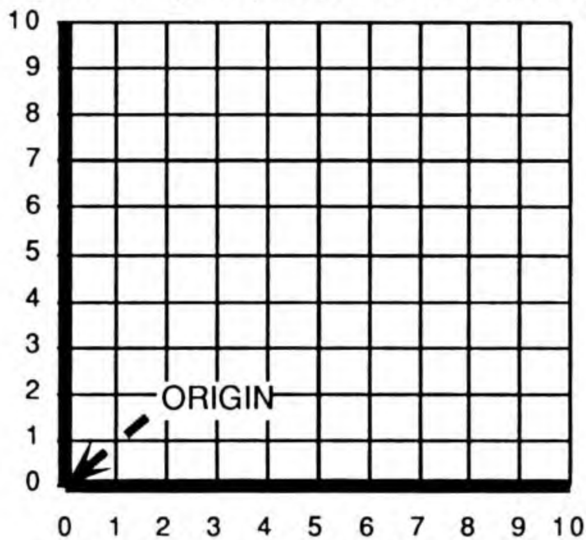
(2) to foreclose on mental blocks to arithmetic, randomness, & algebraic symbolism and abstraction.

A teacher following this prescription should answer all the student's reasonable questions, but resist any impulse to instruct in the meanings of the principles until the students gain some familiarity through practice and demonstration. Explanations remain secondary to gaining acquaintance with concepts like graphing, uncertainty, variability, and abstractions.

Graphing Standards

By examples, the children can learn the conventions of graphing in many different formats that experienced people take for granted. Instruction begins with the *Cartesian coordinate system*, the standard rectangular grid. The horizontal scale is the *abscissa*, sometimes called the x-axis and often designated as the time axis. The vertical scale is the *ordinate*, often named the y-axis. Let the children hear the names, but don't hold them responsible for knowing them.

Each scale has a zero reference point, and where they coincide is the *origin* of the system, as shown here. Most frequently,

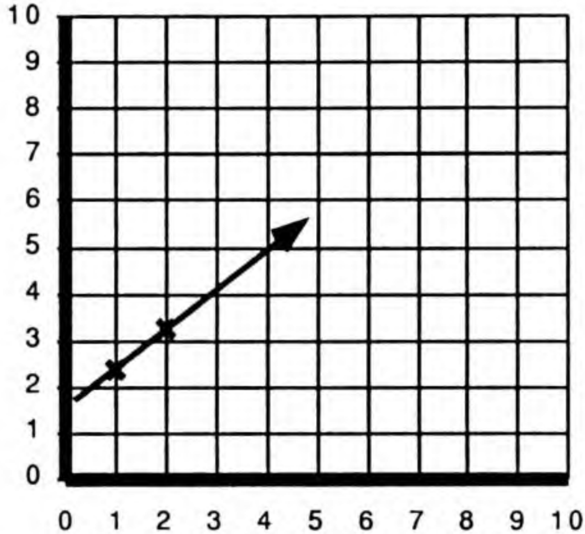


LOCATING THE ORIGIN

Figure 5-1

the origin is the lower left corner of the chart, as shown, and that is where instruction should begin. This is true in the most elementary situations. It is also true whenever the data are unsigned, as occurs in many of the upcoming examples.

Students will quickly grasp that the abscissa normally increases to the right and the ordinate increases up. This elementary chart indicates positive growth by a line that rises to the right, as shown in this second diagram.



USUAL POSITIVE GROWTH

Figure 5-2

When time is a parameter, it is usually the abscissa. Sometimes the abscissa is an unordered value axis, and sometimes the ordinate is the number or frequency[2] of occurrences.

---

[2]Frequency in this sense means *relative number.*, that is, the number at each datum divided by the total number of observations.

Parameters, Symbols, Values, Dimensions, and Units

While students make measurements, the teacher or a teacher's aide might record the results in tables. This method will train the students in the operational meanings of *parameters, symbols, values, dimensions*, and *units*.

Record, symbol	Parameter, symbol	Dimension, symbol	Value ± Accuracy	Units
Judy, J	Height, h	length, l	4,3 ± 1	feet, inches
Mark, M			4,6 ± 1	
Bunny, B1			3,11 ± 1/2	
Blake, B2			4,3 ± 1/2	

DATA TABLE
Table 5-1

Other tables might begin as shown next. Each row stands for the first row in a different table.

Record, symbol	Parameter, symbol	Dimension, symbol	Value ± Accuracy	Units
Chick 1, C1	Weight, w	force, F	3 12 ± 1/2	pounds (#) ounces
Angle e, e	Angle, ∠	1	37 0 0 ± 5	degrees (°), minutes ('), seconds (")
Blue Blocks, Bb	Count, x	1	13 ± 0	number
Red Box, RB	Volume, V	length * length * length, l^3	14 ± 1/2	cubic centimeters (cm^3)

SAMPLE DATA TABLES
Table 5-2

The tables underscore some ideas to teach children:

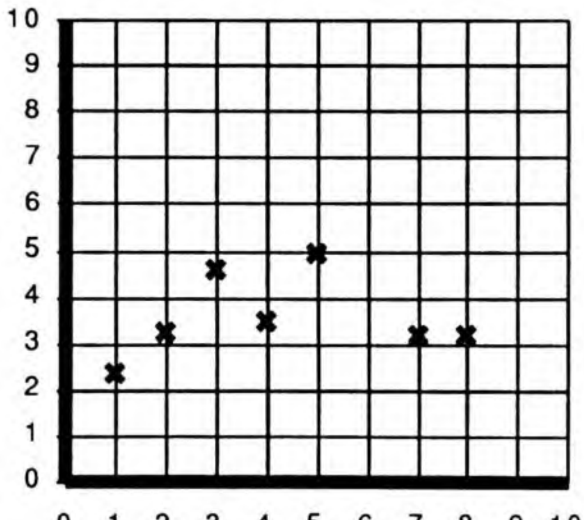
* Every item, including records, parameters, and dimensions, usually has both a name and a symbol, which mean the same thing.
* Every measurement has its associated accuracy.

In the earliest measurement experiments, children will not understand "±" or a reading of "1/2". The teacher might explain simply that the mark ± means that the reading might be bigger or smaller. For the first experiments, children will understand ± 1 better than ± 1/2.

As shown, some units can also have symbols. In later grades, introduce the functional notation. For example, represent Judy's height as h(J), saying "h of j".

Plotting & Follow-the-Dots

The teacher should make graphs in two modes. The first is direct, placing points on a chart as students collect each datum, as shown by this figure of work in progress:



FIRST QUADRANT PLOT
Figure 5-3

The alternative is indirect, using a table as an intermediate repository for the data. The dynamics of real time plotting has much greater visual and mental impact, and is the preferred introductory technique. Graphing from tables is better scientific technique. It is more practical when children collect data outside the classroom. After a few demonstrations, the children should be able to put points on the charts themselves.

In the beginning, the teacher can connect the data points follow-the-dots fashion without apology, as shown here:

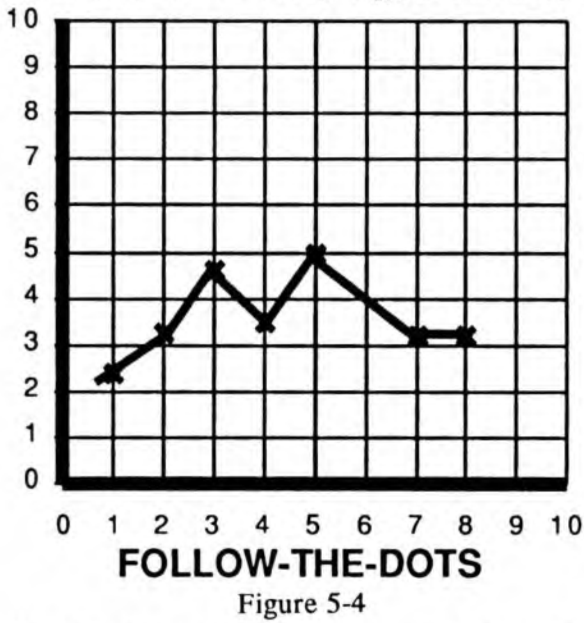


Figure 5-4

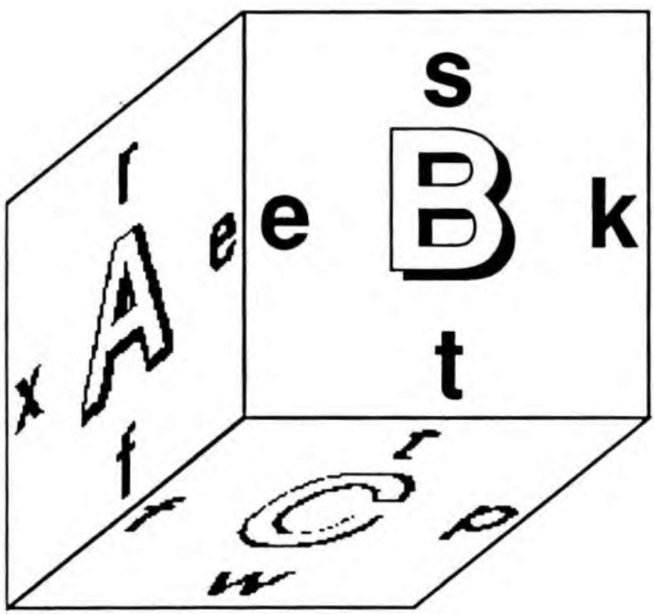
Follow-the-dots improperly suggests a model, or at least the novice might unknowingly draw this common erroneous inference. For more about this Follow-the-Dots Pseudo-model, see *models* in Chapter 6.

For a brief period each day, children should concentrate on this process of practiced objectivity. Later when the children have learned elementary arithmetic, the process of data reduction can begin.

Length

Measurement training begins with the dimension length. The agenda is to measure just about everything conceivable in the environment.

> Kids should measure everything in the room. Label the faces and edges of familiar objects like building blocks, using names or symbols. Give direct names to each feature, and semi-symbolic names like Side 3, Edge 2. Include symbolic names, as in labeling the faces of each rectangular block A through G and the edges random letters, as shown here.

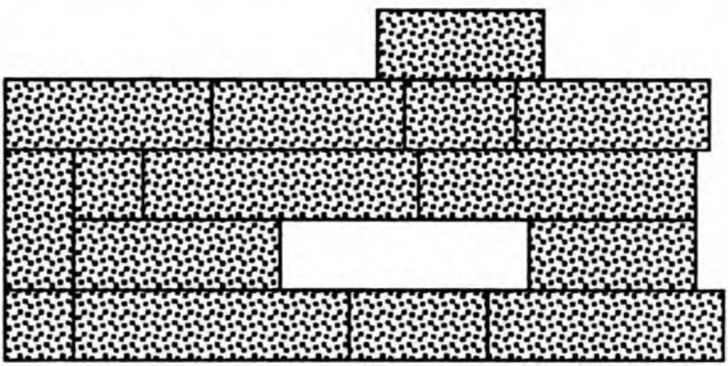


LABELED SOLID BLOCK

Figure 5-5

Measure the height or length of plants as they grow, plotting the measurement against the ordinate finding the date of the measurement along the abscissa. Ivy-like plants, like garden peas, will grow geometrically. Other plants like flowers may follow a geometric acceleration pattern early, and then as maturity is approached, exhibit a geometric deceleration. The resulting S-curve will educate the youngest student, and the analysis of growth rates can serve to illustrate logarithmic plotting for advanced grades.

Make a game out of having one group of children specify the dimensions of a block to fill a space in a wall or a puzzle, while another group searches through a supply of blocks for one that fits.



BLOCK WALL

Figure 5-6

Calipers of several varieties are handy tools for children. They range from large uncalibrated devices, usually made of wood and available from art stores. More elaborate models include inexpensive mechanic's tools with linear and angular scales, and on to precision micrometers which are quite dear. Homemade calipers will work quite well. With these tools, children individually can measure or compare the sizes of objects.

> Children should measure one another. Measure height, arm length, long bone length, head depth and width. Measure arm, neck, and head circumference. Initially, the teacher should take the data and plot it on a bar graph.
>
> Make a set of dowels of graduated lengths for making height comparisons before the pupil is ready to read a meter stick. Each child could find his height by matching to the closest dowel. Have the dowels labeled as 3,4, 3,4 1/2, and so on. Old broom sticks and mop handles will do nicely.
>
> Make primitive linear measurements with sticks marked in integers. Have the students make measurements to the nearest mark and to the greatest mark less than the object. Add marks for halves and repeat the experiment. Add quarters and repeat. When this process becomes familiar, introduce standard rulers and yard and meter sticks.
>
> Measure the arm span of each child, and plot it against his height.

Part of the training is to teach students that the parameter of length is the applicable characteristic of the dowels. For example, if a dowel is a 3 meter standard, then the label *3* refers to its length; it is not a name for that dowel. Two sets of dowels represented by their lengths, such as {3,1,1/2} and {3,3/4,3/4}, are not the same except for the sum of their lengths. The property of addition upcoming in the student's education will represent the sum of those lengths. From experiments, the student will have already learned the associative and distributive laws of addition. Therefore, to emphasize the assignment of a value to length, make the dowels of different materials, such as wood and metal. Use different widths and cross sections. Paint them different colors. Allow the students to acquire the knowledge of the property represented by a "3" on wood stick with a square cross section and by a "3" on a thin circular cylinder in steel.

The student will be getting a practical introduction to fractions and decimals by reading the scales on their measuring sticks before they have any theory.

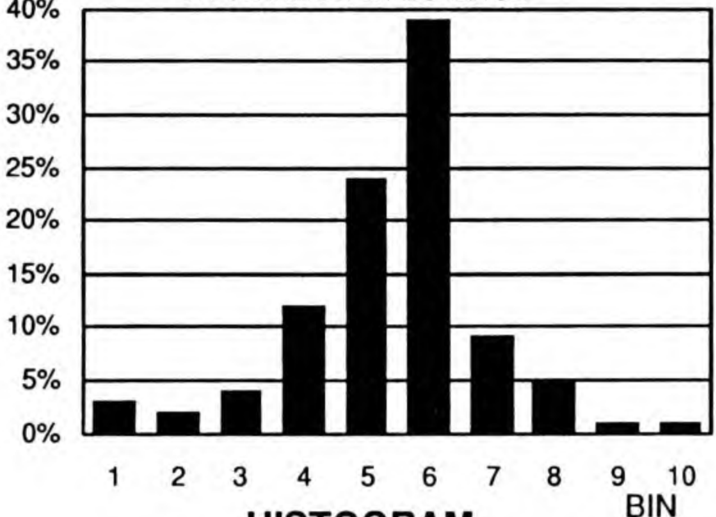
When students begin to get bored with standard length measurements, perhaps in middle grades of elementary school, add some variety like the following exercises.

> Provide an engineering scale ruler or a homemade version of such a scale. One side of the scale might read inches, while the other side reads 5 feet per inch.
>
> Let the students measure the features of scale models of objects like jet airliners and police helicopters and models of animals using different scales. Make tables of the results.
>
> Let the students measure the features of a scale model of a dinosaur. Have the students figure the size of a box a museum would need to ship an assembled skeleton of a dinosaur.
>
> Have the students sketch a picture of a common beetle available as a model in the classroom. Have them measure the features of the beetle, such as legs, body length, body width, body height, antenna length, and portray the measurements on the sketches.

The Histogram

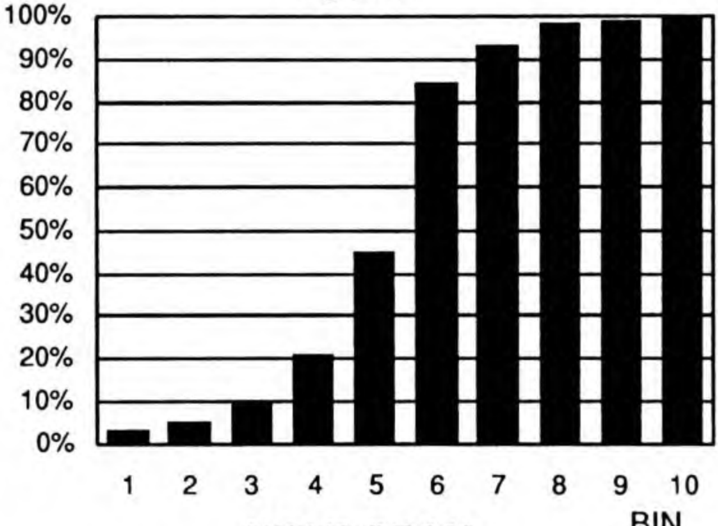
If accurate measuring devices are available, the teacher can show how the results may be compared for statistical variation within a sample.

> Borrow a micrometer. Measure the lengths in a bag's worth of cheap nails. Make histograms of the density and the distribution of results.



HISTOGRAM
DENSITY OF NAILS

Figure 5-7

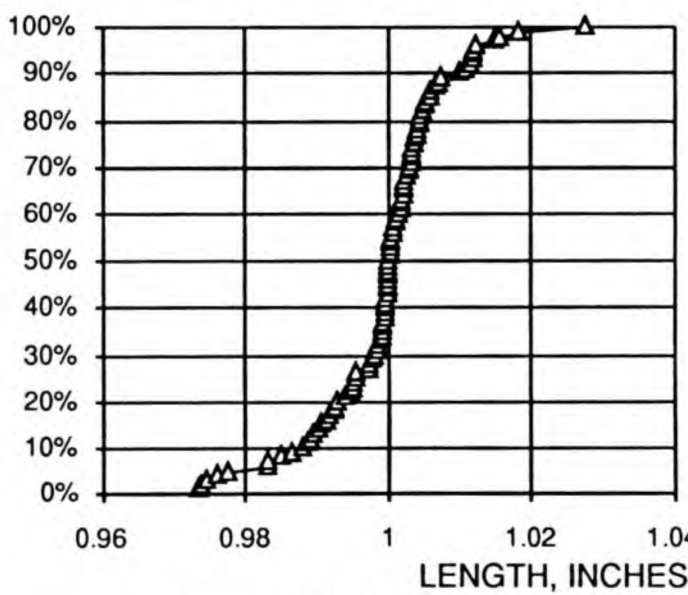


HISTOGRAM
DISTRIBUTION OF NAILS

Figure 5-8

(See footnote for a brief technical discourse.[3])

[3] The titles of the two charts emphasize the difference between the concepts of density and distribution, where distribution is the cumulative subtotals of the density from the left. Standard , "cook book" statistical procedures dictate the use of histograms. However, histogram analysis is a flawed process and the problems with it lie deeply buried in the literature. First, the appearance of the density is especially sensitive to the arbitrary positioning of the cells. Furthermore, the density is not statistically guaranteed to converge, meaning that increasing the sample size cannot guarantee that the density gets closer and closer to the underlying probability density. By a theorem due to Parsons, convergence can be guaranteed statistically for the distribution function. A superior technique and one better suited to computer calculations is to rely on the distribution without bins. To make such a distribution, compute a data point for each sample value. That data point is the percentage of all samples less than or equal to the given sample, as shown below.



DISTRIBUTION OF NAILS

Figure 5-9

Volume

Following are some volumetric experiments.

Familiar objects like cartons from various dairy products make a useful set of primitive volume measuring devices. Containers like soft drink bottles are also good, and many are available in the U. S. to metric standards as well as U. S. standards. Calibrate each container, establishing a fill line or cutting them to that level.

Kitchen utensils will serve well. Let the students experimentally determine the conversion factors between liquid measures, all the way from teaspoons to gallons. Sand is a perfectly suitable alternative to water.

> Measure the volumes of cafeteria containers and other containers brought from home.
>
> Have the students measure the volume of their shoes and hats. Here, dry sand may be the preferred medium.
>
> Have a handyman make cubic buckets, one foot on a side, one inch on a side, and one centimeter on a side. Let the students experiment with how many gallons there are in a cubic foot, cubic centimeters in a cubic inch.

Two dimensional plotting

Map reading is excellent training as the precursor to two dimensional plotting:

> Prepare a map of the neighborhood in which the children live. Have them locate their residences, schools, markets, fire stations, and police stations.

The recommended procedure is to fit a (cumulative) probability distribution function to this curve. Then, for the density function, compute the slope at each point (i.e., differentiate) the function or compute estimated bin contents by taking differences between points on the fitted distribution function.

(This should work except where bussing or apartment living makes the map impractical.)

Prepare a map of a fictitious city with street names and addresses ordered in the usual sense using only the conventional north east quadrant. Have the students locate addresses.

Plant gardens outdoors or in window boxes. Make maps of the location of the plants with the students help, and have them locate plants.

Weight

Here are some experiments with weight. They couple well with those on volume and length. Adding graphics gives an early feeling for density, a concept weakly understood by students currently entering the University of California!

Provide scales in the form of fish scales, market scales, bathroom, and kitchen scales. Don't worry about accuracy or calibration yet. If possible, provide balance, spring, and counterweight types. Have a handyman make a simple balance beam with fulcrum and baskets. Show the students measurements in ounces and pounds, and in grams and kilograms. Let them determine conversion factors experimentally.

Weigh each child in the room. Make plots by age and by height.

Weigh the measuring dowels and plot the weights against the length.

Weigh the standard volumetric measures when filled with water, then with sand. Plot the data from the experiments on the same graph, showing two straight lines emanating from the origin. The slope is the density of the media. Note that having unit volumes eliminates any dividing.

Have the students try to divide the dry measure of containers into two equal piles. Measure the two results and graph.

Plane Geometry

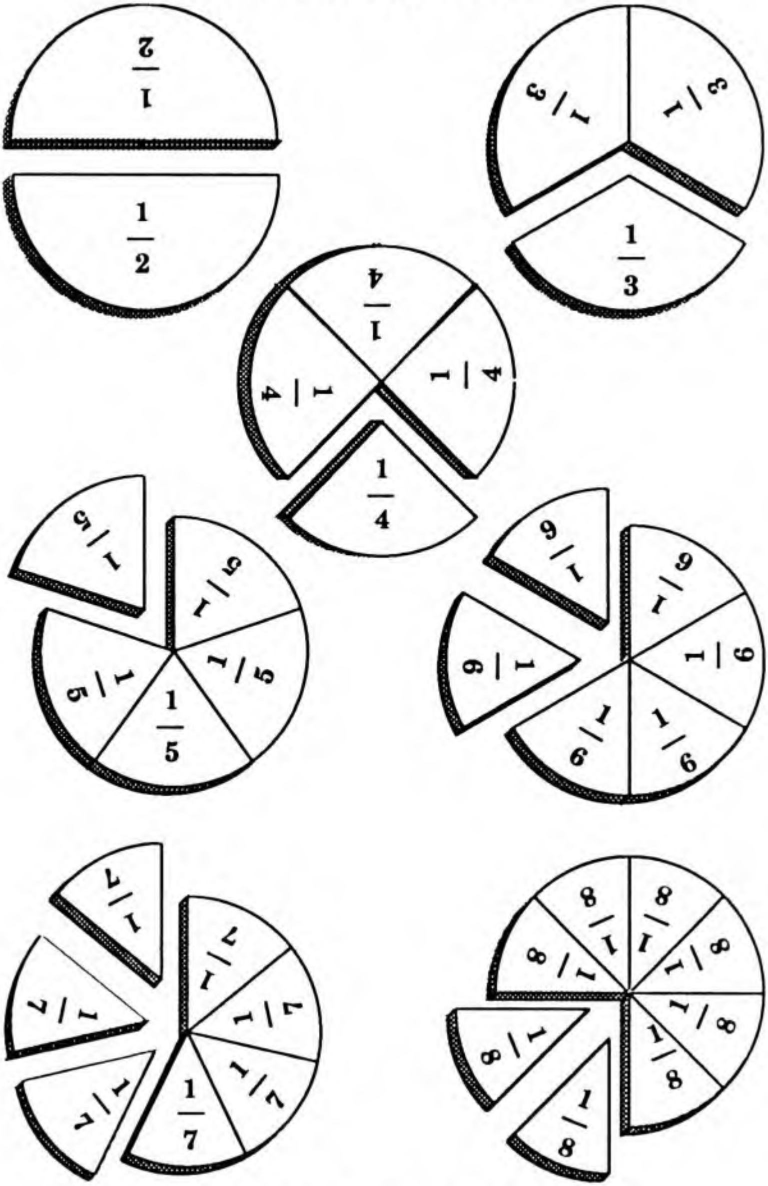
Here is some K-1 plane geometry for little Euclids:

Have a handyman make a large set of plane geometry figures from plywood. Paint them, and label them with names. Label their features, like sides, angles, perimeters, and chords. Have the children measure the angles in various triangles using a protractor. Record and plot the results in histograms.

> Have the students measure the opposite sides of squares and rectangles. What did they learn?
>
> Have children measure the circumferences and diameters of circles. Plot the results and discuss the result.
>
> Have the children determine by measurement which plywood circles will lie down inside the one cubic foot bucket.
>
> Find true North by finding a true East to West vector with the shadow of a stick. How might the Egyptians have used this technique to orient their pyramids?

Students can become familiar with the ideas of projections of spaces by experimenting with solid geometric figures. These figures are standards that satisfy the requirements for measurement by comparing.

> Provide the students with several regular, solid geometric figures, including spheres, cubes, square and circular cylinders, circular cones, tetrahedrons, and so on.
>
> Make several complete sets of wooden disks cut into pie-shaped segments each with a hoop or wooden pie plate to hold them. Label each segment with its proportional size: 1/2, 1/3, 1/4, and so on. Let the students experiments with filling the hoop with different combinations of segments. (See the figure opposite.)
>
> What can students learn about the shape of the sun, the earth, and moon by studying these solid figures?



PLAY PIES

Figure 5-10

> The sun and moon look like disks. Which solid figures could look like disks when viewed from different angles?
>
> Do we see different angles of the moon? Does the moon rotate on its axis? How much?
>
> How might we know that the sun rotates on its axis?

Time

> Determine the age of each child in the room from his birthday. Make plots of the age density and distribution. Approach the problem incrementally. Make a histogram of ages according to the year and month of birth.
>
> Teach children to tell time on a conventional analog clock missing the minute hand so that they have to measure the travel of the hour hand between hours.
>
> Make various cumulative histograms of birth month, showing those on or before each year and month, and those born before each year and month. Make a cumulative plot of those born on or before each birthday in the class.
>
> Time events like relay races. Determine winners by the shortest times.
>
> Make a sundial in class. Calibrate it against the school clock. Are the hourly spacings uniform? Discuss with the class.

Sound

> Demonstrate the musical scale and use it to reinforce graphical techniques. Use a picture of the piano keyboard as the ordinate and time marks as the abscissa to plot a tune.
>
> Measure the wavelength of a vibrating string. Show how to measure wavelength with an oscilloscope.

Calibrate the piano scale by wavelength, creating an early demonstration of a logarithmic scale.

Temperature

Measure indoor and outdoor temperatures. Use linear and dial types of thermometers. Measure hourly temperatures during different seasons. Plot the results according to the time of day and the season. Measure body temperatures discretely, as in the crook of the arm. Measure inlet water temperatures; measure them by seasons.

Take wet-bulb temperature readings. This requires a sturdy thermometer that a child can swing through the air when covered with a wet rag.

Place a pot of water over a burner. Measure its temperature continuously as it warms, while it is boiling, and as it dries. Plot the results to show the region of *conditional stability*.

Growth rates

Grow plants in window boxes and hydroponic tanks. Count the number of seeds that germinate, and determine the ratio of those that germinate to the total (the à posteriori probability of germination).

Measure the heights of the individual plants daily, record in tables, and plot the results in graphs.

Weigh flower pots or hydroponic tanks daily as plants grow in them; record and plot the results. Compensate graphically for the daily evaporation in soil by timing the measurements and the watering. Show how keeping the liquid level constant in hydroponics overcomes the effect of evaporation on measuring plant weight gain.

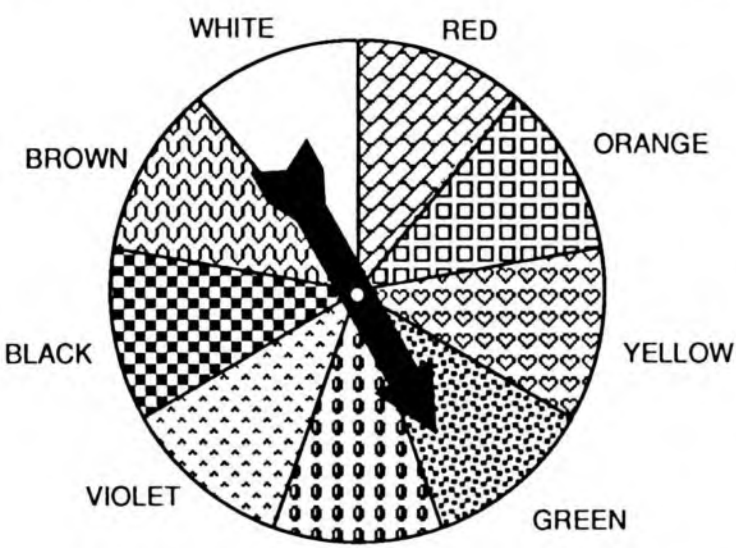
Make comparative studies, growing plants in different conditions of light or with different watering and feeding regimens. Measure height. Grow plants in containers easily connected to a fish scale. Weigh them as the primary measure of growth in individual and comparative studies. Compare results of height and weight studies.

Raise chickens, rabbits, or mice. Weigh them regularly from infancy to maturity, recording and plotting the results. Weigh their daily food intake. Plot length of various features against weight.

Probability

Students can begin their probability training by plotting random walks.

Have the children plot the progress of their favorite baseball or basketball teams along with the competition. Add one to the teams positions for each win, and subtract one for each loss.

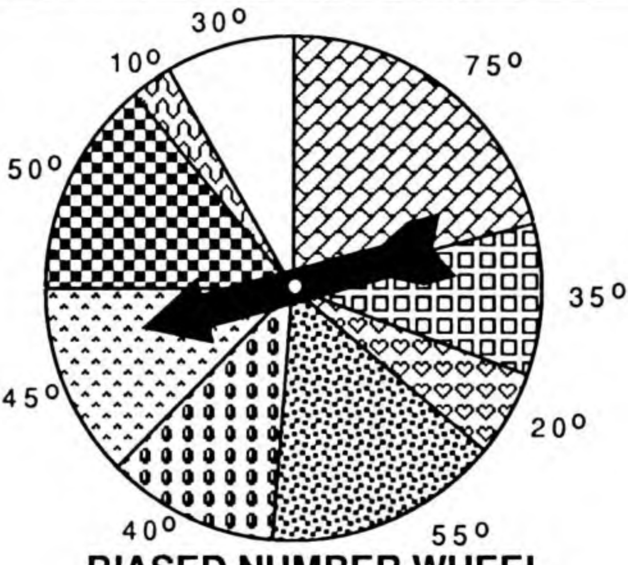


CONVENTIONAL NUMBER WHEEL

Figure 5-11

Probability source data are readily created in the classroom using a basic number wheel, fashioned after the pointer in a child's board game. Something of this sort should be in every classroom from Kindergarten through grade 6 or so. A few years of simple training like this will keep the children's minds open to non-deterministic thinking for their lifetimes.(For more on this paradigm, see Rade (R70).)

> Have a handyman build a large model, balanced to operate smoothly when mounted vertically. Make the segments distinctive colors. Nine segments might be useful, named with the six colors of the rainbow plus black, brown, and white.
>
> Have a handyman make a model of the basic spinner, but instead of equal segments, give them randomized widths. Here is a model marked in degrees.



BIASED NUMBER WHEEL

Figure 5-12

> Use the wheel to call on students for participation, to determine the next activity of the day, to select teams for games, and so on. It works like a television game

show. Adapt a pair of number wheels to demonstrate sophisticated concepts like conditional probability and biasing.

Have the students measure the angle of each segment. The teacher can demonstrate graph making with the results, where the abscissa is the color name and the height is the angle measured.

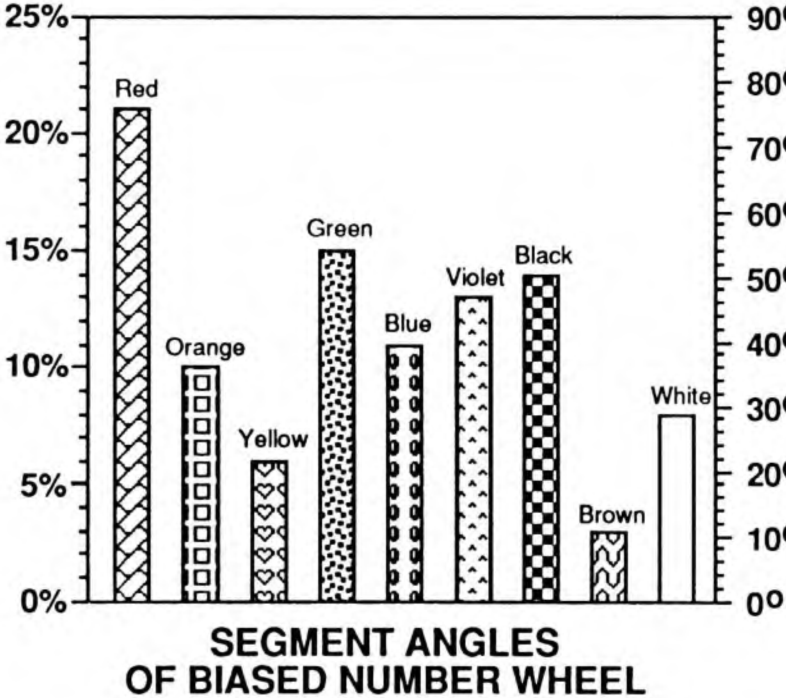
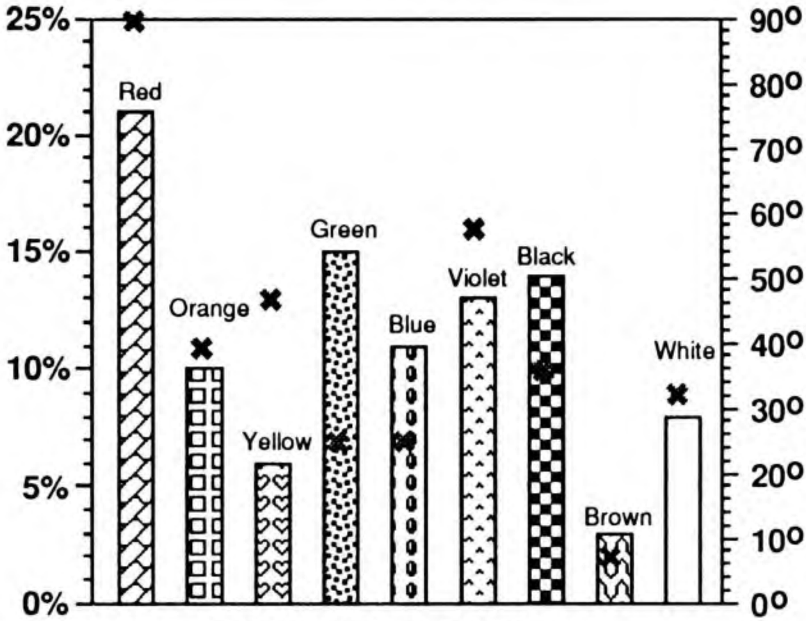


Figure 5-13

Have the students spin the pointer, say, ten times each. Count the results in each segment, and plot the count on the same chart as used for the angle measurement:



EXPERIMENT WITH BIASED NUMBER WHEEL

Figure 5-14

The bars are the à priori data, or more properly information, and the crosses are the à posteriori, or experimental, data.

The Biased Pointer

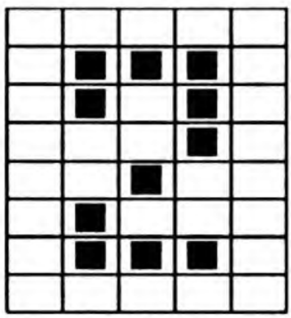
Add a small weight to the pointer to bias it. With the spinner mounted vertically, repeat the experiment.

As described, the spinner experiment reinforces graph making and demonstrates à priori probabilities (here, probabilities proportional to the angle width) compared to à posteriori probabilities (measured frequency of occurrence).

Signal-to-Noise

Here's a simple, entertaining exercise with profound consequences.

Make a white card containing an array of squares, much like a crossword puzzle, with 5 columns and 8 rows. Within the center of the card in the 3 by 6 sub-array, blacken squares to make a figure. The example here has 11 blackened squares to make a figure 2.

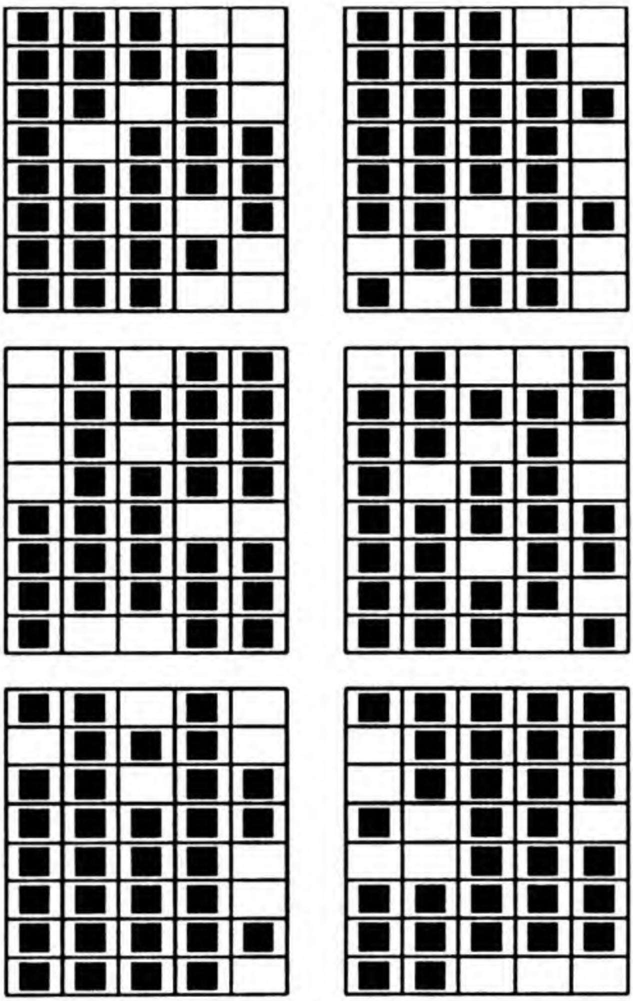


PERFECT FIGURE TWO

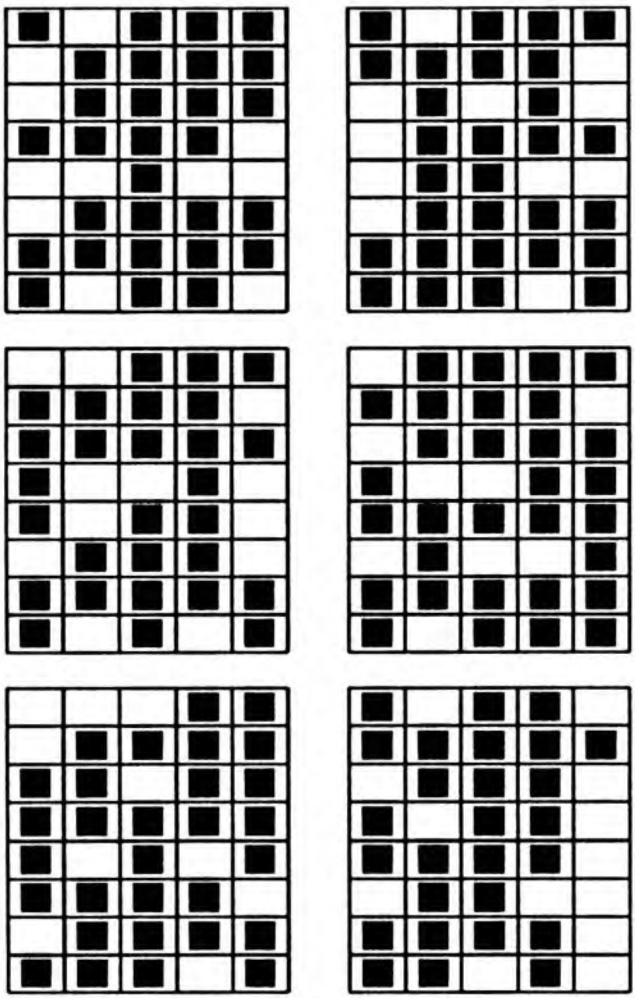
Figure 5-15

Make a copy of the card for each student. Have each student blacken the white squares according to a throw of a die. The criterion in the example is to blacken each square when the number on the die is 4, 5, or 6. The result is a well obliterated figure for each student. A dozen examples appear in the figures on the next two pages.

Now make a master card of the individual results by voting amongst the students. Progress around the 40 squares, blackening those squares for which the students, cards are unanimously black.



FIGURES TWO IN NOISE
Set 1
Figure 5-16A



FIGURES TWO IN NOISE
Set 2
Figure 5-16B

> The result is that the master card reproduces the entire original figure with a small number of false alarms, depending upon the class size. With as few as 12 students in the class, the chances of a perfect result (no false alarms) is about 80%.

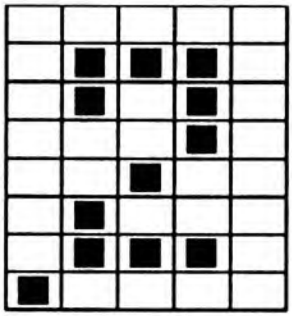


**FIGURE TWO
ESTIMATION
EXPERIMENT**

Figure 5-17

This is an example of the effects of processing to enhance *signal to noise* ratio. The figure on the original cards is the *signal*. The die casting adds *noise*, in this case without subtracting noise from the signal. Tallying votes reproduces the signal. The unanimous voting cancels the noise if only one low number occurs in the room. The processing adds the signal *coherently* and the noise *incoherently*.

Other examples like this experiment for pattern extracting are easy to design. The model is stronger if you let the noise subtract from the signal as well. You may also vary the thresholding and voting schemes, which will change the quality of the result. For other alternatives, use a finer resolution, and demonstrate the reconstruction of the signal if the cards are allowed to be misregistered one or two cells.

ADVANCED EXERCISES

Some advanced demonstrations with calculations:

> Demonstrate a concept as simple as addition with the plane geometry figures. Measure the perimeters of the various polygons and the separate sides. Demonstrate that a tape measure is an analog of an adding machine.
>
> Children who have learned addition should add the angles in the various figures to see what they might discover.
>
> Measure the furniture in the room. Make scale drawings of the room.
>
> Make plots in polar coordinates, measuring angle and distance.
>
> Children who have learned division may start making slope measurements. The plot of circumference against diameter of various circles will yield Π.
>
> Devise experiments to measure viscosity, solubility, hardness, color, reflectance.
>
> Have each child make a rain gauge using a plastic milk carton cut off at the top. Weight each carton with a stone, and place them in an array on the playground. After a 24-hour rain period, bring the cartons in, remove the stone, and measure the water content. Plot the rainfall across the playground area. Estimate the average rainfall over the whole area. Estimate the rainfall rate (inches per hour). Estimate the variation from gauge to gauge, assuming a constant fall everywhere. Do the rainfall measurements indicate a pattern, a mean trend?

Designers of curricula can add measurements of spring constants, compressibility, light diffraction, and many other topics.

CHAPTER SIX
SCIENTIFIC METHOD

INTRODUCTION

Scientific Method lives! Not as a procedure followed sequentially through numbered steps, but as a set of criteria for the end product of science. It is neither a recipe nor a road map, but a checklist of criteria which can be met by any route — inspiration or perspiration, methodically or haphazardly — reserving for the scientist-to-be, lessons in procedural efficiency

The Strategy identified seven distinct elements of the method in the preceding chapters:

1. Definitions
2. Observations
3. Measurements
4. Models
5. Predictions
6. Experiments[1]
7. Validation

These seven elements, shown in logical order, lend themselves to a useful taxonomy, one that is compact and uses familiar terms descriptive of the whole process.

Language and Definitions

The first logical step in the Scientific Method is the setting of precise terms for the discourse. The defining process links language, logic, and mathematics inextricably.

Researchers have found common, elementary grammatical structures in unrelated languages. In at least one instance, children of first generation Creole-speaking parents introduced grammar into the primitive tongue. Grammar appears to be hard-wired in the organization of our brains. Research might show a similar relationship one day between languages, the brain, and logic.

---

[1]Including passive experiments, such as monitoring geological phenomena, social behavior, economic activity, and disease processes.

Arguably, all languages contain the same logic. The logical meanings assigned to semantic relationships existed in man's languages before logicians formalized them. Perhaps we inherit mathematics as well. If the logicians are right, then mathematics is but a school of logic. Semanticists only need establish that all languages contain integers.

All three subjects, languages, logic, and mathematics, might fall under the name *language*. That's confusing, however, because of the conventional, narrower sense of language as a particular tongue. No sufficiently descriptive term has surfaced for this primitive step in the Scientific Method, and so the Strategy struggles with several inadequate alternatives. Since these subjects are in a sense pre-science, the Strategy lumps them under the term *Foundations*.

Discovery & Objectivity

Discovery and Objectivity are powerful notions, desirable in the taxonomy of Scientific Method. However, they overlap. Objectivity spans both the use of a precise language and measurements used for either confirmation or validation. Discovery fits well the scientific work of uncovering patterns in measurements, which itself is an objective pursuit.

In recent years, *Discovery* has been in vogue in education as a name for the scientific process. However, used so broadly *Discovery* has an unacceptable connotation. It suggests that the Real World possesses not just objects but processes and laws, just waiting unearthing or observing. This is far too deterministic. Science is considerably more complex, revolving as it does around models that are pure constructs of the human mind. Mathematical theorems may be subject to discovery but not scientific laws in all philosophies.

Measurements and Creativity

Discovery needs the counterbalance of Creativity, an essential and stimulating side of science too often overlooked. Some scientific experiments are often major creative feats, as great as the models they test. Finding a novel implication or prediction of a model has a good deal of creative content, for it can lead to an efficient test for validity. Creativity needs equal emphasis in the scheme, especially to offset the implications of *Discovery*.

Discovery includes the field of measurements, which is known by the obsolete name of *mensuration*. Measurements can live up to that name as a horribly dull, dry theoretical topic. Still, the subject is the core of all science. The tactic here is to leave the broad theory of measurements to specialist training for those with a special appetite, emphasizing instead the practice of measurements for general science literacy. So, the Strategy concentrates on developing the intuition for measurements throughout the public school experience. Still some theory remains as needed for the introduction to the theories of probability, estimation, and experimental design.

Patterns and Models

Patterns, like *Discovery,* is a vogue word that suits the purposes of a science strategy. The preference is to preserve Discovery as a major category of Scientific Method that includes observations, measurements, and the extraction of patterns. Models, the core of scientific expression, are actually the expression of patterns from measurements. They are reserved for the next logical step, Creativity.

Predictions, Experiments and Validation

Does validation begin with the invention of the experiment, or does the experiment belong with the creative process? In fact, even making the prediction or finding it in the model can be a consequence of experimental design. Often the initial formulation of a model does not include what later develops as a major consequence or prediction. A prediction can be a subjunctive forecast; that is, the model would have predicted it if someone had only though of it! Quite often, the predictions of the model are consequences discovered by scientists other than the creator of the model.

So placing experimental design under Creativity reinforces the objective of emphasizing the creative parts of science. The data acquisition phases of experimentation can stay with Validation.

Summarizing the progress so far, the Strategy finds seven essential elements for the Scientific Method arising out of the defining of science. Organizing them into four categories produces a taxonomy for the Method. The table below shows the disposition of those seven elements.

SCIENTIFIC METHOD	Essential Elements
A. FOUNDATIONS	
1. Language	1. Definitions
2. Logic	
3. Mathematics	
B. DISCOVERY	
1. Observing	2. Observations
2. Measuring	3. Measurements
C. CREATIVITY	
1. Modeling	4. Models
2. Predicting	5. Predictions
3. Designing Experiments	6a. Experiments
D. VALIDATION	
1. Experimenting	6b. Experiments
2. Confirming	7. Validation

SCIENTIFIC METHOD FROM ESSENTIAL ELEMENTS
Table 6-1

A discussion of each major category of the Scientific Method follows. The emphasis is on the pedagogical aspects for the earliest years for three reasons —

(1) to illustrate the Method,
(2) to show the feasibility of developing an early intuition for elements of science, and
(3) to advance an integration of technical and language curricula into a unified grade school curriculum that promotes science literacy.

Counter-examples

Parapsychology, "UFOlogy", environmentalism and astrology were examples of various forms of human inquiry cited in the prologue, Chapter 1. These schools serve to illustrate the Scientific Method as counter examples. To the four fields already mentioned, add religion along with Creationism, and stock market analyses. Look at their report card, graded using the pass (✓)/fail (Ƒ) system:

	FIELD				
Method Attribute	Astrology & Religion	Environ-mental-ism	UFOlogy	Parapsy-chology	Stock Market Analysis
Defini-tions	Ƒ	✓	✓	✓	✓
Observa tions	✓	Ƒ	✓	✓	✓
Measure ments	Ƒ	Ƒ	Ƒ	✓	✓
Models	✓	✓	✓	Ƒ	✓
Predic-tions	✓	✓	Ƒ	Ƒ	✓
Experi-ments	Ƒ	Ƒ	Ƒ	✓	Ƒ
Valida-tion	Ƒ	Ƒ	Ƒ	Ƒ	Ƒ

FORMS OF HUMAN INQUIRY
REPORT CARD
Table 6-2

Teacher's notes illuminate the scoring:

Astrology & religion: Two similar-scoring fields. No definitions. No laboratories. No experiments. Apocryphal observations; no measurements. No statistics. Ample models & predictions featured! No validation. Lots of falsifications.

Environmentalism. As distinguished from the scientific field of ecology. Elements of good science, but notorious cases adapted to foreign domains with little more than carry-over of good definitions and models. Theories demoted to conjectures absent both observations and measurements, e.g.,

ozone holes	increased incidents of cancer
nuclear winter	human destruction of species
global warming	power line radiation hazards
increased acid rain	world agricultural decline
land fill exhaustion	increased cataract rate

nuclear power radiation leaks

Confirmation lost when models fail to account for known phenomena, e.g.,

climate	weather
oil spill recoveries	ocean currents
ocean temperatures	atmospheric gas mixture

Dire predictions unsupported by model, e.g.,

mass death famine climatic change
rampant disease excessive deformities

Strong appeals to belief systems and poetry, e.g.,

Balance of Nature "Fragile Ecosystems"
"Delicate Blue Planet" sacrosanct life forms
"Isn't the saving of one life worth ... "

Theories coupled to political agenda, such as

socialism egalitarianism peace movement
Anti-change; anti-technology; anti-science

For additional, responsible views on Environmentalism, try former Governor and scientist Dixy Lee Ray's *Trashing the Planet* (R90). This well-documented, well-researched work must be read by science teachers and journalists.

"UFOlogy": Appearance of science. Apocryphal observations. Unreliable, unrepeatable measurements. No statistical analyses. Contains models with zero confirmation! No predictions! No validation.

Parapsychology: Research with the appearance of science. Lots of Discovery. Formal trappings of clinical laboratories, experiments. Subjective observations, show business stunts. Some measurements, as in ESP, Kirlian photography; even statistical analyses. But no models! Hence, no predictions, no validation!

Stock market analysis: Many trimmings from science, as in powerful statistical techniques. Well-defined, well-observed, measured to exhaustion. Abundance of models, as in technical patterns (e.g., "head and shoulders", "flags"). More predictions than in horse racing. Zero validation! Falsified daily.

These "isms" and movements fail the test for objective knowledge. Every element of the Scientific Method must be at least potentially present to qualify as a science. Application of the Scientific Method produces models with predictive power in the objective world, a result not found in the examples.

Of course, every legitimate field of inquiry contains immature models. These models lack some elements of the Scientific Method, and so are candidates for further advancement. The student, the journalist, or the jurist can easily test any model against the criteria. Daily newspapers are ripe with examples.

Subjective Evaluating

Citizens or scientists are likely to attach a subjective score to any model. On the next page is a formalization of some traditional terms applied to the quality of models. A ✓ means a required element, and a O means a missing element of the Scientific Method. The names used in this subjectiverating scheme in themselves are not the important part. Instead, they convey certain ideas to the public about claims to scientific knowledge. The classification might say that a particular model has little scientific foundation, or that it has yet to demonstrate its required predictive value.

	Rating System[2]				
Method Attribute	Non-Science	Conjecture	Hypothesis	Theory	Law
Definitions	0	✓	✓	✓	✓
Observations	Possible	Possible[2]	✓	✓	✓
Measurements	Possible	0	✓	✓	✓
Models	Possible	✓	✓	✓	✓
Predictions	Possible	✓	✓	✓	✓
Experiments	Possible	0	0	0	✓
Validation[3]	Not Possible	0	0	Partial	✓
Comments	Lacking definitions, no sharable observation, measurement, model, prediction or experiment	Lacking measurements, model has no confirmation[3]. Any experiment would have produced the first confirmation or falsification	Model with predictions & confirmation, but unvalidated. Any experiment would have produced partial validation or falsification	Some validation shared, but regarded incomplete. Experiments responsibly questioned, incomplete or lack breadth	Solid repeatability. No sensible experiment remains that would do more than sharpen domain

Scientific Model Rating Scheme
Table 6-3

Following is a description of each quality rating, including some illustrative examples.

---

[2] See discussion in Chapter 5 relative to the possibility of objective but unmeasurable observations. If such a thing exists, give the

1. Conjecture. An incomplete model or a model adapted from another domain and unsupported by relevant data is a conjecture. A conjecture is little more than a guess, educated or not, about a pattern between measurements, real or hypothesized.

- Cold Fusion: The model for fusion that occurred in the widely publicized Fleischmann-Pons experiment does not account for the accuracy of that experiment nor for validated, conventional models that predict a flux of radiation absent in the experiment.

- Greenhouse Model of Global Warming: a conjecture since no measurements exist of increased surface air and water temperatures, increased sea level, increased latitude of ice caps, or increase in so-called greenhouse gasses other than CO_2. Scant measurements suggest increased average temperature due to higher night temperatures, but Global Circulation Models (GCMs) make no day/night distinction. Further, this theory does not span the data of the natural cycle of CO_2 as estimated from ice corings, for example, nor does it account for the poor performance of existing GCMs. Warming predictions replaced previous warnings of a coming ice age![4]

---

theory credit for the measurement.

[3]*Confirmation* here has a supportive sense, referring to a part of the model's foundation in measurements, to the Real World object or phenomenon observed and modeled. A *confirming* datum is relevant to the model but not falsifying. *Confirming* is an incomplete form of corroboration, a form that builds or accumulates. In our definitions for science, the word *confirmation* has been freed for reuse, and it suits the purposes here quite well.

[4]The most pessimistic prediction of 8°F warming is about half the historical estimates for the range of temperature excursions. (A maximum of about 27°F warmer than today reached 40M and 80M years ago, and a minimum of 30° cooler about 15,000 years ago.) A peak to peak variation of 8°F dominates the climate history of the past 8000 years with a cyclic period of about 800 years. The chances

- Model of Ozone Depletion by CFC: a conjecture since it extrapolates from laboratory results to the free atmosphere, it does not span the normal ozone cycle of creation and dissociation in the upper atmosphere, and it depends on weak models for climate and solar activity.
- Health Foods.
- Nuclear Winter.
- Oort Cloud: A repository of comets just outside the solar system, based on little more than the fact of comets.
- Sun's Binary Companion: A "black" star on a 26 million year orbit around the sun that might disturb the Oort Cloud, causing a rain of comets that might account for an apparent periodicity in mass extinctions on earth.
- Thought Experiments: Mental models invaluable to teaching, often precursors to the creation of important models.

2. *Hypothesis.* A model based on existing data which has yet to begin validation, is a hypothesis. A hypothesis is a shared relationship based on disclosed à priori or à posteriori knowledge, and absent any falsifying instance.

- Extension of the Laws of Physics and geological theories (Uniformitarianism) throughout all time or space.
- Steady State Cosmological Model: Fitted to known data.
- DNA Fingerprinting: Unique DNA per individual (1:1), except identical siblings, well supported; probabilities of process or handling errors unquantified. Accuracy of 1:n needed, researchers working on determining n are beginning to report results based on law enforcement data bases.

3. *Theory.* A model based on existing data with supporting confirmation and no counter examples is a theory. This

---

of an ice age might be great enough for man to prepare to warm the planet deliberately.

category is quite broad, covering relatively novel ideas to models arbitrarily close to qualifying as laws.

A theory is a hypothesis that has at least one instance of validation. That is, one fact has met all the premises of the hypothesis and confirms the prediction of the model. Scientists can usually measure the strength of the model statistically. The best known tool is the numerical confidence level, which measures the probability that any confirming results are not due to chance alone. The public might be confused by the fact that a 50% confidence level is the floor of this measure, for it means that results are a coin toss. In other words, the results contain no information.

Subjective criteria are available for assessing the elegance or robustness of models. These include

smallness of the set of variables,
à priori, experimentally supported basis, and
scope or importance of the predictions.

Here are some examples:

- Plate Tectonics: A well-supported theory still under modification to include new data on other currents of material in the earth's crust.
- Quarks: An unfolding model with great successes in predicting particles.
- Epidemiology of Acquired Immune Deficiency Syndrome (AIDS)
- Theories of Special and General Relativity
- Probability Theory: Even with the great power of the theory, and the embedded Laws of Probability notwithstanding, the theory has some troubling subjective aspects that keep it from canonization as Law.
- Big Bang Cosmology: Approximately as valid as the competing Steady State Cosmology, except for the confirming data of the background radiation. Based on expanding universe, which is based on presumption of the

Doppler effect, which is based on the fact of the Red Shift[5]. Could the Red Shift be caused by some other phenomenon than velocity, as for example inertia of light?

Several contemporary books are available which promote science literacy by surveying modern scientific models in layman's vocabulary. Stephen Hawking's book *A Brief History of Time* (H88), introduced in an earlier chapter is fascinating though unearthly reading. It has enjoyed a long run on the non-fiction best seller list. Two books contain brief vignettes in the form of rather encyclopedic collections of topics. To cram on a subject for chit-chat at a party, or just for bedside reading which is much shorter than a short story, try *The New York Times Book of Science Literacy* (F91) or Hazen & Trefil's *Science Matters* (H90).

4. Law. A model validated in all possible ramifications to known levels of accuracy is a law. A law is a model of extraordinary confidence, especially so when it contains an à priori justification or foundation. Scientists practiced in the discipline have broadly validate the model eliminating all outstanding questions or reasonably competing models.

- Laws of Thermodynamics
- Molecules, atoms, stable elementary particles (photons, electrons, neutrinos, protons), etc.
- Conservation Laws, including momentum, angular momentum, mass, energy, quantum numbers.
- Newtonian Laws: The status of laws for Newtonian mechanics is upheld by restricting the domain to non-relativistic conditions.
- Newton's Law of Gravitation: Which led along a troubled path to the great predictions of planets previously unobserved.

---

[5]Even the Red Shift rests on the assumption that atomic spectra are universally constant (Uniformitarianism in the astrophysics domain).

☛ Mendelian Laws

Sufficiency, Utility, Elegance, and Power

Sufficiency and utility are two important qualities widely used as subjective ratings for scientific models. Sufficiency comes from the application of the principle in science that the simpler model is preferred. Scientists and philosophers prefer the theory with the least number of assumptions. They look for the least number of coincidences, using the least energy to effect and employing the fewest variables or parameters. This is the elegance discussed in Chapter 3, and is a subjective indication of quality.

An excellent example of sufficiency is the model for the evolution of life. Having three forces in nature, evolution, environment, and life adaptability, somehow operating in synchronism is substantially weaker than a model based on a single assumption. (The Strategy presumes to offer such a simpler model in Chapter 10.)

Supplementing the quality factors of model rankings, simplicity, elegance, and power, is the idea of utility. The more useful a model is, the better it is in some subjective sense. Utility need not mean practical use as in a technology, but simply as scientific novelty. Science gives its highest marks to a model that predicts a previously unsuspected phenomenon or opens a new avenue of scientific pursuit, practicality notwithstanding.

Evaluating science fields and models is now a measuring process. It is objective, except for the few subjective quality factors added above. The standard for comparison is the derived Scientific Method. Since evaluating is in part science, it is part of the Scientific Method. This allows the Strategy to complete the Scientific Method, albeit rather self-referentially:

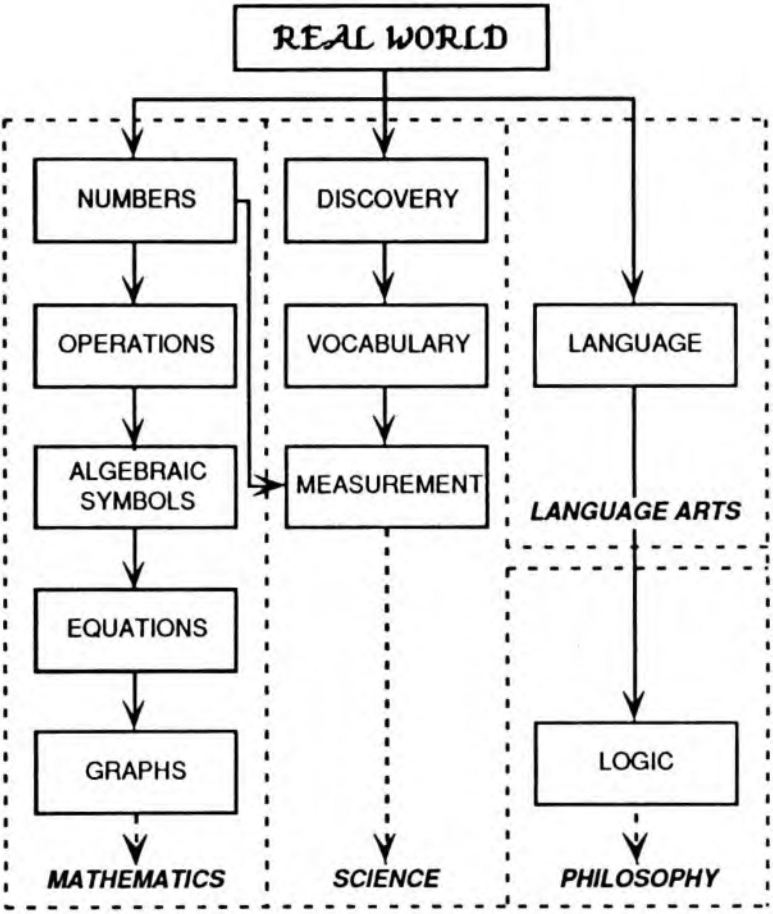
A. FOUNDATIONS
   1. Language
   2. Logic
   3. Mathematics
B. DISCOVERY
   1. Observing
   2. Measuring
C. CREATIVITY
   1. Modeling
   2. Predicting
   3. Designing Experiments
D. VALIDATION
   1. Experimenting
   2. Confirming
   3. Evaluating

COMPLETE SCIENTIFIC METHOD
Table 6-4

CURRICULA

Traditional technical curricula introduce graphing as the representation of algebraic equations. This introduces several unnecessary levels of abstraction and obscures the power of graphs to represent experiments. The next two figures portray this idea.

Standard curricula teach algebraic symbols as abstractions of numbers. From a mathematical standpoint, this is necessary and sufficient. From a scientific standpoint, it is neither! Since numbers themselves are either purely abstract objects or are abstractions of certain properties of objects, a symbol for a number is a two-level abstraction, an abstraction of an abstraction. Moreover, this exposure is likely to occur first late in a child's development, typically in Algebra I at age 14 (grade 9).



TRADITIONAL TECHNICAL CURRICULA

Figure 6-1

This nesting of abstractions may be written as

SYMBOLS(NUMBERS(OBJECT ATTRIBUTES)).

Read this as "symbols of numbers of object attributes". Following the sequence of the mathematical curricula, graphs are five levels deep:

GRAPHS(EQUATIONS(SYMBOLS(NUMBERS(OBJECT ATTRIBUTES)))).

The degree of abstraction, also conveyed in the figure above, is a formula for concept failure in children. Too many abstractions are traditionally series dependent. If an individual "doesn't get fractions" or gets lost the first time the teacher says, "let x = the number," then he is off track to a timely understanding of graphs. This series model for mathematical entities enables a single mental block to halt intellectual progress.

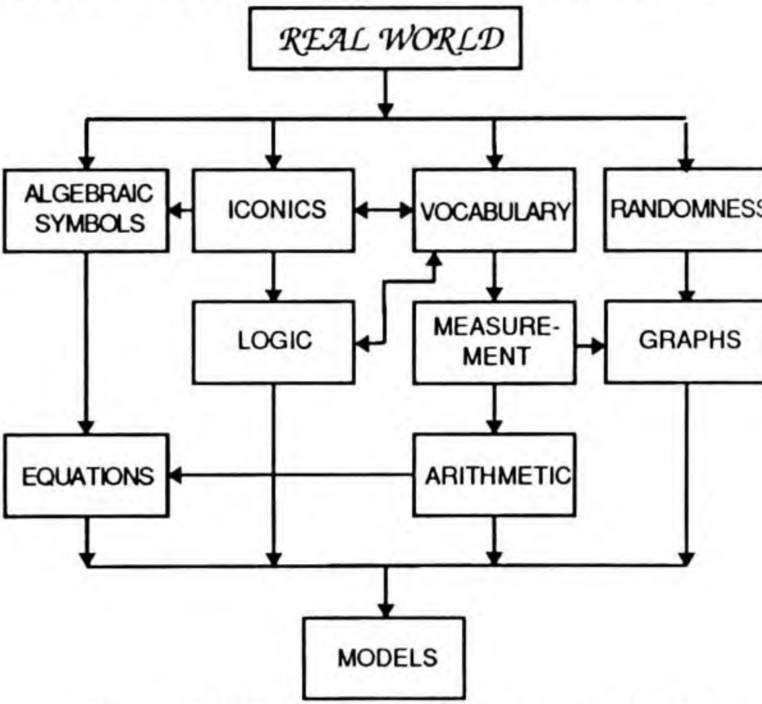
A number associated with an object attribute is a measurement. In the most elementary form, it is a count, as in 12 edges to a solid figure or three leaves to a branch. More often, the measurement is a real number with an error that is another real number.

Developing proficiency with numbers beginning with classical algebra is unnecessary. It promotes the concept that measurements are errorless integers or rational fractions. This deprives the student of the rich experience of understanding the quality of measurements, and reinforces the mental block of deterministic thinking.

Classical teaching may introduce measurements in natural and physical science curricula at the high school level. This cheats the student of many opportunities to develop his intuition and to benefit from mutual reinforcement between subjects.

In science, algebraic abstractions represent not numbers but parameters of the Real World. A good practice for science is to select symbols for equations that are abbreviations of names for the parameters to the greatest extent practical. Even in the most esoteric, mathematics-rich field of information science, algebraic symbols stand for physical quantities of information. No technical field is more attune to this condition than computer programming. Programmers ran out of symbols long ago, and use English-like names for parameters as they would algebraic symbols. The idea here is to introduce algebraic symbols as short hand notation for physical parameters.

The Strategy is to train students to develop familiarity with abbreviations of this sort before introducing algebra as the symbolic manipulation of number abstractions. The procedure recommended here is to integrate the curricula for science, mathematics, and language into a single program built in support of the scientific method, as shown below:



SCIENTIFIC METHOD CURRICULUM
Intuition Before Theory
Figure 6-2

Graphs now display data before equations. Students learn about graphs from the class of à posteriori or experimental events, rather than the à priori or theoretical world. The two will be merged, but each student will have a readily accessible and understandable mental model to support acquisition of theories.

A. FOUNDATIONS

Language

Objectivity enables people to share ideas and observations unambiguously. It begins with precision in language and its derivatives. Precision refers to the disciplines of using natural language with maximum clarity and extracting logic from it. It leads to abstractions and eventual mathematical representation, if possible. In one sense, these are precursors to science, and in another sense they are defining the terms of discourse as the first step in science.

In the United States at least, there is no substitute for English. The Strategy can abide no excuse for not upholding the highest standards of proficiency in English for all students. In particular, English as a Second Language and bilingual education effect a much lower standard.

Keys to English. Language training must include both phonics and etymology, the keys to English. Teachers should disassemble and dissect words at every opportunity. They should regularly show the roles that letters have in phonics, and that root forms have in word meanings. Accurate, accent-free pronunciation leads to orthographic understanding and the ability to read with meaning. Every student deserves that valuable information coincident with his first training in reading. That information in itself is scientific.

Hang signs like those on the next page in the language-enriched classroom along with pictures of the beasts. (Note that the English words are in normal characters, and the word roots in italics.) The appeal of these prehistoric critters to children is pandemic. Invite them to make up new names, like "fish eyed" (ichthyops) or "bird toothed animal" (ornithodon) and try to pronounce them! Skill required: elementary reading and phonics.

dinosaur = *dina-* + *saurus*

Brontosaurus = *bronto-* + *saurus*

Ornithopoda = *ornitho-* + *-poda*

Triceratops = *tri-* + *cerat-* + *-ops*

bront-, bronto- = thunder

-odon, -odus = having teeth

din-, dina- = terrible, mighty

ichthy-, ichthyo- = fish

ornith-, ornitho- = bird

-poda = having feet

pter-, ptero- = feather, wing

saurus = GR. lizard

-ops = eye, face

tri- = three

cerat- = horn

COMBINING FORMS
FOR PREHISTORIC CREATURES

Figure 6-3

These are inviting codes or puzzles for the children to translate. (These definitions are broadly applicable to science. A comprehensive list of combining forms appears in Appendix B.) At the tope of the next page are some advanced recommendations.

Etymology is to vocabulary as phonics is to reading. The analogy of phonics to etymology is not complete, but it is strongest in science. English is a phonetic language; letters

-onym =
GR. word

ec- =
household, environment

etymos =
GR. true

-ism =
doctrine, belief system

ecology =
ec- + *-ology*

etymology =
etymon +*-ology*

-logy, -ology =
discourse, study

etymon =
GR. word meaning

COMBINING FORMS FOR STUDIES

Figure 6-4

have their origins in sounds. In a similar way, the roots of words and pieces of words (prefixes, suffixes, and combining forms) provide building blocks for new words in English. To the engineer this is *gain*.

By learning the tools, the technician can build many things. This is gain. Analogy: "Give a starving man a fish, and you feed him for a day; teach him to fish and you feed him for a lifetime." This training removes much of the grind of learning, reducing the overburdening mental lumber of memorization to truly manageable levels. It replaces drudgery with the keys to a lifetime of vocabulary building and reading. The system should expose students to this part of knowledge at the first opportunity, well before they understand it.

Taxonomies. Taxonomies help define words in their context, and help demonstrate the completeness of definitions. Students should get the earliest possible exposure to taxonomies, for they teach an organized way of looking at things. The archtypical taxonomy is the biological classification schema, whose major categories are

Kingdom
  Phylum
    Class
      Order
        Family
          Genus
            Species

Biologists define a subclass for each of these rankings, along with several other specialized transitional categories. Each major category in biology has somewhat standard or accepted rules for nomenclature.

The classification principle is as applicable to any technical endeavor as it is to biology, so students should learn about it early. Examples should be on display in classrooms and used from time to time as references. Tables of contents in texts or handbooks, or the Propedia to the Encyclopedia Britannica might be useful sources for creating other examples.

A data base structure is a modern variant of a taxonomy. It is a basic tool in the development of most software applications. Examples should be available in elementary form from software developers or in texts for students to ponder, if not study. Following is a two-level example created from a familiar human interface to personal computers. Each level provides the precise name for a software entity, such as a menu or a subroutine. Its attributes, included in parenthesis, are subsidiary software entities.

Main Menu (File, Edit, Window, Sort, Special, Dictionaries, Calculator, Chronograph)
  File (New, Open, Print ... , Close, Duplicate)
  Edit (Undo, Cut, Copy, Paste, Swap)
  Window (Arrange ..., Select ... , Initial Conditions)
  Sort (Alphanumeric ... , Date, Size, Kind, Color)
  Special (Quit, Restart, Eject, Format ...)
  Dictionaries (Spell Check, Grammar Check, Definition, Thesaurus)
  Calculator
  Chronograph

Logic

"If it doesn't rain today, we'll take recess outdoors!" And the Kindergarten class with "cabin fever" cheers. Man has been able to utter and understand such elementary hypothecated statements long before he discovered logic. Do the private languages of twins contain constructs like these?

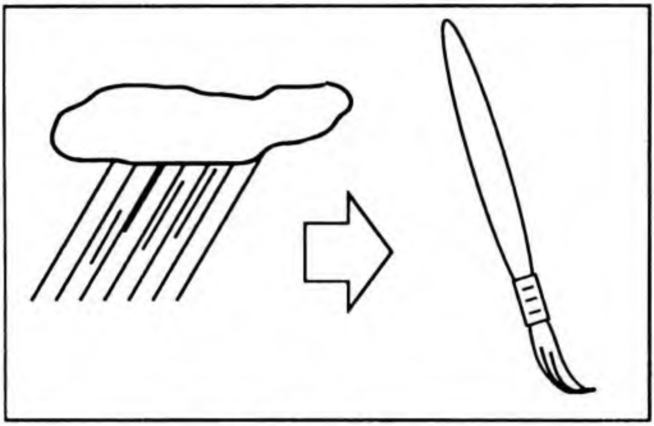
Now how are the youngsters going to react to the next direction?

> "If you want a hot dog or a hamburger and French fries, get in the first line!"

What is person who wants a hot dog but no fries supposed to do or think? The language is natural, but it is ambiguous.

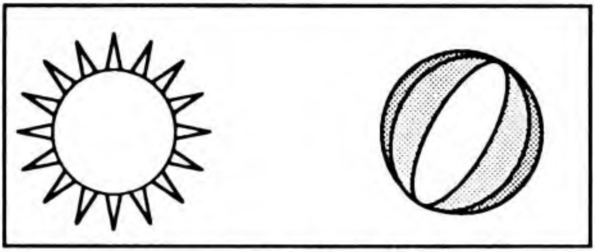
Modus Ponens in Pictographs. Children need exposure to the structure and meaning of these expressions with their first formal language training. It might begin with symbols even before they can read, especially since it works for chimpanzees! The art has the name *iconics.*

Start by explaining these two symbol sentences to the class:



IF IT RAINS, THEN WE'LL PAINT!

Figure 6-5



IF THE SUN SHINES,
THEN WE'LL PLAY BALL!
Figure 6-6

Change the symbols to express other familiar ideas to the class. Students should quickly learn the IF ... THEN structure, and that the arrow stands for that construction. Then change the direction of the sentence so it is written right-to-left or top-down, making sure that they know the meaning didn't change. Skill: estimate entry level Kindergarten.

The children will have learned that when the sun actually does shine, the event "play ball" occurs. They will have learned Modus Ponens, the most elementary rule of logical inference.

Letter Abstractions. Later, replace symbols with letter abstractions of the sentence clauses:

$$\mathbf{R} \Rightarrow \mathbf{P}$$

At first, give the letters significance, as R means rain and P mean paint. Later drop the letter significance, but keep the relevance of the sentences to real activities of the class.

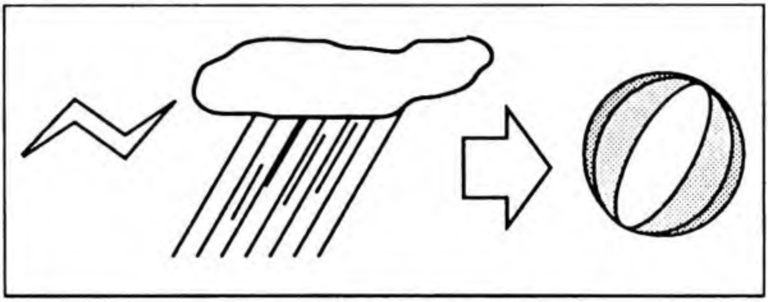
This process will give the students an intuition for symbols, abstractions, and logic while they are most receptive. Later, when formal training begins in mathematics, algebra, and logic, they will have an intuitive foundation that supports the new theory. Skill required: the alphabet

As the class advances, pretend that you can't remember if it rained or not one day last week. Yet you do remember that you didn't paint that day! See if you can elicit from the class that it must not have rained that day. By then they will have developed a familiarity with Modus Tollens, the next most elementary rule of inference.

First Logical Operator, Not. Teach them "Not" by symbols. One standard method uses the prefix symbol,

$$\sim$$

that rather appropriately resembles an N, standing for negation. It might look like lightning in this next pictograph:



IF IT DOESN'T RAIN, THEN WE'LL PLAY BALL!

Figure 6-7

The other standard is the overstrike. So we have two equivalent symbolic sentences:

$$\sim \mathbf{R} \Rightarrow \mathbf{B}$$

and

$$\overline{\mathbf{R}} \Rightarrow \mathbf{B}$$

either of which children should learn to read as, "If it doesn't rain, then we'll plan ball."

Truth Tables. Introduce truth tables in early grades. Coax young students to supply the implied answers in the third and fourth columns.

B	R	~R	~R ⇨ B
False	False	True	False
False	True	False	True
True	False	True	True
True	True	False	True

ELEMENTARY TRUTH TABLE
Table 6-5

Instruction in logic needs to keep pace with the acquisition of natural language and mathematics throughout the K-12 program. The possibilities for entertainment and development are limitless, reaching right to the frontier of modern mathematics and science.

Remember the story of two kangaroos running toward one another? Just before they came together, they both jumped into the air. They came down in one another's pocket, and just disappeared! This would make a fine cartoon for the classroom. It is a translation of one of the great problems in mathematics which also translates into the following paradox presented earlier:

THE BOXED SENTENCE IS FALSE.

Post this sign in grade schools for all who enter to ponder and relish. Skill required: elementary reading. More about this paradox appears in Chapter 7 and Appendix A: This Appendix is False.

Symbolic logic is the formal extraction of certain meanings imbedded in our language. Symbolic logic refers to classical deductive logic in any of several valid forms. As to induction, the Strategy agrees with the Encyclopedia Britannica that the distinction between deductive and inductive logic is obsolete, and that science has absorbed inductive logic.

Mathematics

Mature, well-trained individuals are often unable to acquire even elementary mathematical skills when first exposure occurs late in life. Senior executives, including some who trained as engineers, find themselves unable to learn the art of planning for business uncertainties with statistics and probability distributions. Chefs who never learned fractions can't scale recipes. Students who never recovered from their first encounters with algebraic symbols find themselves excluded from the most exciting science and technology careers. Women who yielded to "math anxiety" are unable to compete for top jobs.

Mathematics historian Eric Temple Bell titled one of his books, *Mathematics, Queen and Servant of Science*. So it is, and so it is that mathematics training must be relentless and apace of science education. A mathematics substrategy to the science strategy can make this happen. It consists of two tactics:

1. Attacking specific mental blocks , such as those interfering with understanding
    - Randomness
    - Graphics
    - Fractions
    - Abstractions
    - Arithmetic binary operations & their properties
2. Developing the intuition before theory
    - Mathematically enriched environment

Absorption according to the individual's personal developmental time table & absorption rate
Non-threatening environment

The strategy is to expose students to à posterior mathematics, reserving the à priori for the more mature and experienced. This means experimentation before theory. In this way, the system provides a reference basis for learning abstractions. The Strategy also involves providing a nutrient-rich environment, waiting for each brain to develop on its own time table.

Mental Blocks. The first four barricades, randomness, graphics, fractions, and abstractions were targets of the approach to teaching objective thinking in Chapter 5. Demonstrating randomness was the direct goal of the number wheel experiments and of the game with the obscured numeral "2". Developing the intuition for randomness was also a goal of the various measurement experiments, where the variability inherent in measurements was evident in the data presentation.

A feeling for graphics is the foundation of model building. It supports a visual intuition for interpolation and extrapolation, data smoothing, and model fitting to data. These are the essence of elementary models.

The approach to fractions was to employ fractionally marked measuring sticks, the calibrated dowels. Lengths marked in integers, halves, quarters, and so on, are a first step. Add thirds. Make separate pieces in lengths of 1/2, 1/4, 1/3, 3/4, and 2/3, suitably marked. Let the children learn to add lengths and compute equivalents by experiment.

The approach to abstractions employed several techniques. First, pictographs substituted for sentences, and then letters substituted for the pictographs. Letter labels placed on the blocks became names for features the children were to measure.

Binary Operations in Arithmetic. Most adults have a grasp of the applications of the elementary arithmetic operations of addition and multiplication. If the garden hose is going to stretch across a 20 feet drive way and 40 feet of lawn, add the numbers to get a required length of 60 feet. So, most people know enough not to buy a 50 foot hose for such an application. If a new tire for the family car is going to cost $50, and we need four of them, most of the adults in the family are going to solve the problem by multiplying $50 by 4.

Going a small step beyond this most basic level is not so straightforward. Designers of tests for children routinely invite the naive to perform the wrong process. Multiple choice questions about an area are likely to have the perimeter among the selections. Then there is the classic work problem from first year algebra: Garfielda can mow the lawn in 2 hours. Her brother Tab can do the job in 3 hours. How long does it take them to mow it working together? The paradigm of supplying two time numbers along with the operator *and* creates the temptation to add the two times together. This is pedagogical entrapment! Why shouldn't addition be appropriate? When is addition correct and to what does it apply? In the work problem, the sum of the mowing times yields 5 hours. Simply having the brain engaged is enough to reject the result. If a job takes longer with help, then perhaps this is a problem in labor relations, not mathematics. Do we look for a different formula only because the superficial answer is wrong? Do we guess at formulas, or worse, use cook-book formulas?

Why does a model for a particular phenomenon call for the product rather than the sum of two parameters? What does an area mean, and why does it call for the product of two parameters? Is a law like the attraction of gravity like an area since it includes the product of two masses? What is the intuition for such questions, and where is it developed? In fact, has development of the intuition ever been an objective of science education?

In the simple example about automobile tires, multiplication represents repeated addition. The Strategy strives to develop an intuition that multiplication also applies in scaling, in rate or ratio problems, and in models that are statements about proportionality. Again, the plan is for the student to perform and learn from experiments or demonstrations prior to exposure to the theories.

Properties of Real Numbers. Somewhere rather far along in a student's grade school experience comes the introduction to the properties of real numbers. For the mathematically inclined, the table below summarizes these properties symbolically for the two binary operations, addition and multiplication.

Laws	Addition	Multiplication
Closure	$a+b \in \Re$[6]	$ab \in \Re$
Commutative	$a+b = b+a$	$ab = ba$
Associative	$a+(b+c) = (a+b)+c = a+b+c$	$a(bc) = (ab)c = abc$
Identity	$a + 0 = a$	$a*1 = a$
Distributive	$a(b+c) = ab+ac$	
Cancellation	$a+c = b+c \Rightarrow a = b$	$ca=cb \wedge c \neq 0 \Rightarrow a = b$

PROPERTIES OF REAL NUMBERS
Table 6-6

Every student should have first hand experience at developing an intuition for these properties long before hearing about them in algebra. Following the principles in this strategy, training begins at the first possible opportunity in anticipation of the reinforcement.

The property of closure requires no special training. Any child who would raise so sophisticated question about the number system bears watching. Instead, expect students to presume closure. The commutative and associative laws of addition are suitable for demonstration with measuring sticks in Kindergarten.

[6]Read, "the sum of a and b is a member of the Reals", where a and b are presumed to be represent real numbers.

To teach the unified, scientific method curriculum, the earliest classrooms will be measurement laboratories, containing elements of an elementary physics and natural science laboratory. Algebraic symbols first appear as labels for entities in the child's physical world, as in the building block of Chapter 5. Full appreciation of the letter and number symbols will come when the child first learns to recognize the alphabet and numerals. Kindergarten children should be immediately receptive to the icon abstractions, if experience with primates and illiterates is any indicator. The pictographs lead to experience with symbolic logic and serve as a basis for algebraic symbols to stand for ideas, clauses, or sentences.

Training with probabilities and randomness begins immediately with the number wheel and other experiments using objects familiar to children. These provide opportunities for graph experiences almost coincidentally with measurements, but one level of abstraction earlier. This occurs because the number wheel itself serves as a Real World object.

B. DISCOVERY

Observing & Measuring

Measurements can begin as soon as children can read numerals provided they have sufficient vocabulary for instructions on what to measure. This is the dependence of measurements on vocabulary, on an unambiguous description of the object of the measurements. A measurement is dangerous when made on an ambiguous entity. It misleads, giving an impression of precision and objectivity that masks error. Measurements training reinforced by elementary statistical methods fuels random process training. The combination of these methods provides the young mind with the intuition for scientific accuracy and the foundations of epistemology.

How do humans communicate measurements? Perhaps the most common technique is the data table. As popular as data tables are, they are unfriendly to humans. Most likely the popularity of the table arises from the public's lack of graphical literacy.

Graphs & Abstractions

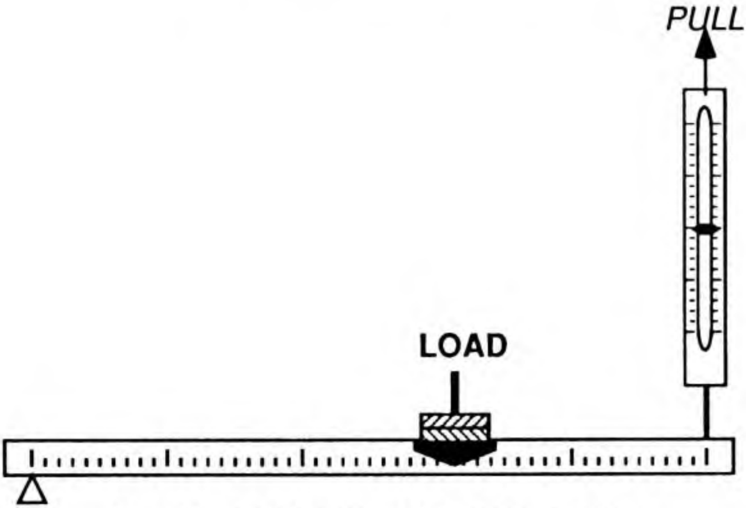
The graph is an image of a set of measurements or of an experiment. It quickly conveys the properties of data, including trends, cycles, patterns, and spread or consistency. It is the vehicle of choice for demonstrating many scientific models or at least consequences of the models. The graph provides the visual image of interpolation and extrapolation.

Like iconics and algebraic symbols, graphing is a type of abstraction. This time the abstraction is an image of an experiment or a series of experiments in which patterns or trends are evident. Instruction in graphing can begin in two dimensions. Locating positions on familiar maps is a good first step. The process more or less absorbs the traditional method of first locating numbers on a number line. Using the upper right Cartesian coordinate leads the student directly to locating points on the positive number line of the abscissa and ordinate.

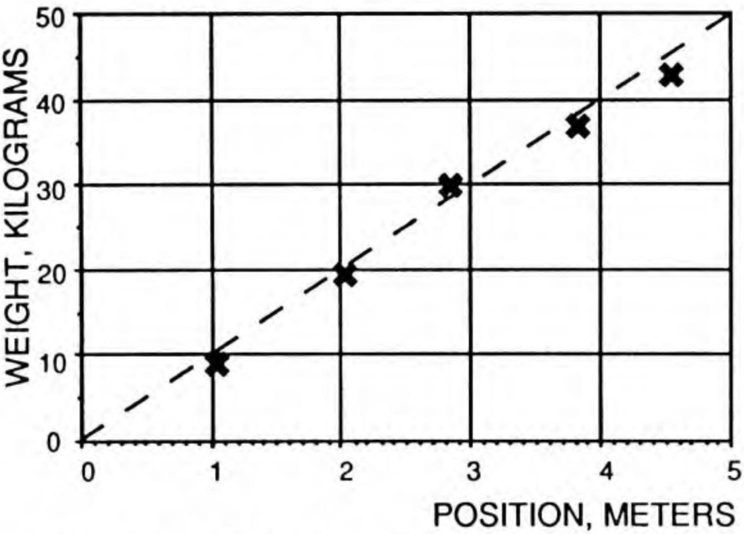
Weight & Force Experiments

On the next page is an early experiment for students who can do little more than read numerals. Immediately below the schematic diagram for the experiment is a graph of results. It should be prepared point by point as the experiment is run so that all the students can watch the placement of points. For this activity, a grid painted on a white board would be ideal.

The procedure is for students to locate the load on a distance scale and read the force on a spring scale. Because this is a laboratory physics experiment, the specification of the procedure defines precisely what to measure. In this experiment, as in all others recommended in this Strategy, procedural accuracy is not the objective. A more important objective is for students to learn to appreciate the errors that occur in all scientific activity, and to learn to measure those errors. To meet this goal, experiments which are obviously not repeatable to the student are ideal.



SINGLE SCALE EXPERIMENT
Figure 6-8



SINGLE SCALE GRAPHICAL MODEL
Figure 6-9

This can be a small experiment mounted on a desk top, or it might be so large that the load represents a child sitting on a beam. The fish scale is only for illustration; a stiffer device like a household bathroom scale may be better to keep the bar level. If the set-up uses a fish scale, students should always pull the scale upward until the bar is level before taking a reading. Ideally, the fish scale will include a method for adjusting for the weight of the bar. A movable weight indicator or scale pointer is fine. If the bar is much lighter than the load, the experimenter can ignore the weight of the bar. For advanced students, the weight of the bar adds to the understanding of the results and to practical experimental methods. For them, the bar should be too light.

To proceed, first set the load at any position and record that position. Then the students should pull the fish scale upward until the beam is approximately horizontal, and someone reads the force on the scale. A plotter locates the point on the graph. Then the class repeats the experiment for many load positions, perhaps one position for each child to keep the interest alive.

As the teacher plots the weights, a straight line will develop. The line here passes through the origin (0,0)[7], implying that a compensation for the weight of the bar is in effect.

Score a success when students understand and anticipate where points are going to appear. This is the germ of graphical literacy. Score a great success when upon several repetitions of the experiment, students begin to appreciate the pattern, the straight-line law, without having it drawn for them. Keep going until they see the evolving relationship.

Score a victory when the students employ the implied model successfully. Move the load to the right; look for students to guess where next data point will fall. This is predicting. Move the weight back until they can guess where intervening

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[7]A standard for notation of a point is a pair (x,y). The designation O is an alternative designation for the Origin.

data points will fall. This is *interpolating*. Work with them until they can guess what the ultimate reading of weight will be on the far right hand side of the graph. This is *extrapolating*. Score a total victory when the students recognize and accept the variability between the straight line model and the data points. The data points will not fit the line exactly, and precision is not desirable at this stage. Sophistication occurs when the students characterize the errors, finding and accounting for patterns in them.

In subsequent grades, the teacher should show students the slope of the line. Like the slope of a hill, it is the amount that the line rises or falls in a unit increment along the abscissa. That slope and the initial position of the line are sufficient to estimate the weight of the object. Thus a model is born in which the ratio or slope is a multiplicand, demonstrating the binary operation of multiplication.

The same experiment supports a model expressed as *proportionality*. This begins the development of an intuition for multiplication as the appropriate operation where parameters exhibit linear proportionality. The basic experiment above demonstrated graphically that the force measured on the fish scale increased in a straight line fashion as the position of the load increased. In English this relation is

Force is linearly proportional to position.[8]

The next step for the youngest student is to keep the position of the load constant, and to change the size of the load. The teacher can record the results on a graph, which will demonstrate a different linear proportionality. This one is

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[8]For the mathematically inclined, this sentence has a number of symbolic representations. Two of the most common are $F \propto x$ and $F = ax$, where F is the Force, x is the distance measured from the left edge of the scale, and a is some number that doesn't depend on x. Constants are local phenomena; one man's constant can be another man's variable.

Force is linearly proportional to weight.[9]

Emphasize that the experiment that first varied position keeping weight constant, and then reversed the roles. No experiment was made varying both simultaneously, which suggests a terribly complex experiment.

The only way that these two proportionality relations for the force can coexist is for the force to be proportional to the product of distance and weight:

Force is linearly proportional to
distance times weight.[10]

Barely literate students can perform the first two tests, varying the size and position of the load. Students on the threshold of learning multiplication can verify the last relation, for example by simultaneously doubling the load and halving the distance.

More advanced students capable of dividing will be able to show experimentally that the arbitrary constant c is the reciprocal of the distance from the origin to the location of the fish scale.

This next experiment demonstrates the principal of moments in mechanical physics. With a little imagination, students who are just able to add can learn the principle of superposition. To provide an intuition for superposition, repeat the experiment with two weights, one fixed and one movable. The results will be that the combined force is the sum of the two forces taken separately. A different straight line results for each position of the stationary weight. That product of the position and the weight of the load is a

---

[9] $F \propto W$, or $F = bW$. This time, W is the weight of the load. The weight need not be known, but it can be doubled, tripled, or more, during the testing. The constant of proportionality, b, does not change as the load size is varied.

[10] $F \propto dW$, or $F = cdW$, where c is a new and as yet undetermined constant.

parameter for the graph, demonstrating another feature in the art of graphing.

Every student should have the experience of seeing relations like those above repeated many times, in one form or another, long before introduction to the symbols or equations, or to words like *moment* or *superposition*.

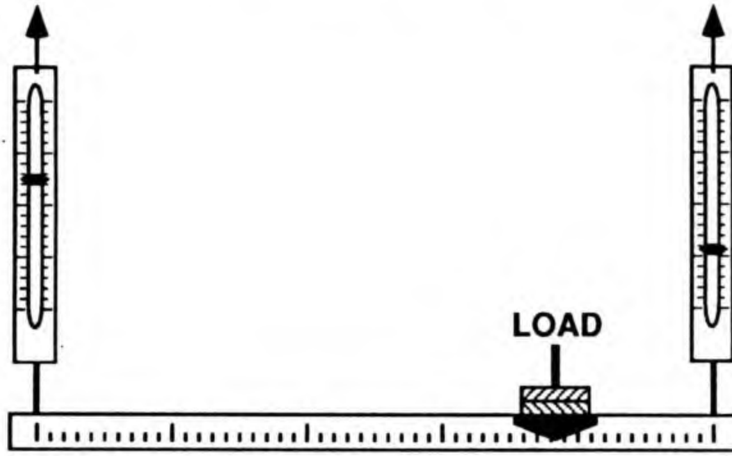
Next is a simple modification to the weight experiment that is suitable for students on the threshold of learning addition. It involves two scales as shown on the right.

The experiment repeats as above, with both scales read and plotted. Two straight lines should result. Now, adding the two readings results in another model. It is the sum of the vertical forces, which by a law of physics totals to the weight of the load! This demonstrates the binary operation of addition; it demonstrates ratios; and it demonstrates a law of physics!

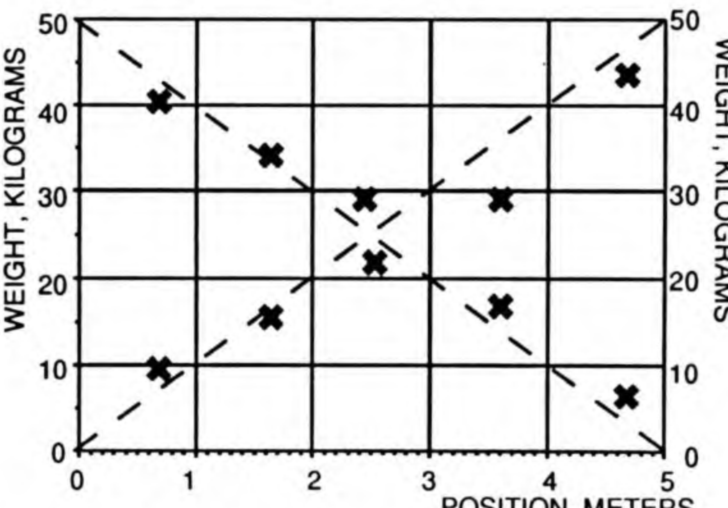
The teacher can demonstrate addition using calipers to add weights measured on the two scales at each abscissa value. The sum should be approximately constant, and equal to the weight of the load.

This experiment showed the effects of using two scales in parallel. Placing two or more scales in series is also useful. Two scales as shown next will provide the same reading except for the additional weight of the lower scale on the upper scale reading. The principle involved is Newton's Third Law of equal and opposite reactions.

Now remove the load, support the series scales so that they lie horizontal, and pull on the chain. The scales should now read the same weight within the limits of their accuracy. Since the weight of the scales does not produce an effect on the measurements, this demonstrates yet another principle of physics. The forces acting at right angles don't contribute to one another (this is a principle of *orthogonality* or of *symmetry*). This experiment reinforces the equivalence between force and weight.

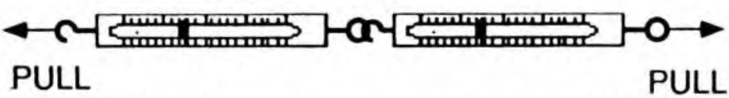


DUAL SCALE EXPERIMENT
Figure 6-10



DUAL SCALE GRAPHICAL MODEL
Figure 6-11

VERTICAL SCALES IN SERIES
Figure 6-12



HORIZONTAL SCALES IN SERIES
Figure 6-13

Algebra of Dimensions and Units

The recommended unified science curriculum builds a mental foundation for algebra, introducing symbols as names for physical entities as early as Kindergarten. This is preparatory for algebra, which in its simplest definition is the arithmetic of symbols. Algebra includes the arithmetic of entities, in particular of dimensions and units. The curriculum should teach this representation, including pre-theory exposure in the earliest possible years.

Dimensions in this sense means the basic parameters of

length [L] time [T] mass [M]
temperature [Θ] charge[11] [Q]

More complex parameters are combinations of these basic parameters; including everyday concepts like

area [L^2]	volume [L^3]
velocity [LT^{-1}]	acceleration [LT^{-2}]
electric current [QT^{-1}]	force or weight [MLT^{-2}]
pressure [$ML^{-2}T^{-2}$]	power [ML^2T^{-3}]

torque, work, or energy [ML^2T^{-2}]

There are many more examples of higher order parameters, like

viscosity [$ML^{-1}T^{-1}$] action [ML^2T^{-1}]

and moments of various parameters, plus a rich collection of electrical parameters.

Units are names for specific standards of measurement for each dimension, such as

---

[11]Other systems or taxonomies are possible. In particular, charge is sometimes a derived dimension, dependent on either the dielectric constant, ε, or magnetic permeability, μ, as the fundamental dimension. The recommended system is to define ε, μ, and other quantities like the gravity constant, G, as relationships between parameters and dimensioned physical constants.

inch	meter	pound	gram	quart
liter	erg	g	calorie	BTU
	ampere	ohm	volt	

Abundant examples await in dictionaries, texts, and handbooks. The units belong to standard sets, including principally the metric system, called the Systême Internationale d'Unités or SI for short, and the two nearly identical systems, known as U. S. and British. The MKSA (meter-kilogram-second-ampere) system is another name for the metric or SI system. It augments and replaces the older MKS system. Two other standards are the CGS (centimeter-gram-second) convention and the Gravitational System.

By far the most common technique for assigning units and dimensions to equations is to define or otherwise establish the system separately from the equations. All too often, the reader is simply left to find a consistent set of units in which the equation will be correct. An equation like

$$E = mc^2 \tag{6-1}$$

is usually interpreted as the profound concept of equivalence between mass and energy. Before Einstein energy was known to be proportional to mass, but Einstein said that the constant of proportionality was the speed of light in vacuum squared. To apply this famous equation in a computation, however, the student will need a reference book or two on dimensions and units. Frequently a careful and thoughtful writer will help by defining the dimensioning of an equation for the reader in the following style:

$$\text{"}E = mc^2, \tag{6-2}$$

> where E is the energy in ergs, m is the mass in grams, and c, a constant, is the speed of light in vacuum in meters per second[12]."

[12] Precisely defined as 299792458 meters/second, or approximately $3*10^8$ meters/second.

These presentations, while conventional, are weak from both the scientific and pedagogical standpoint. An equation in science is not the same as an equation in mathematics. As a mathematical entity, it is a relationship between abstractions of numbers or sets. In science it is an abstraction of a statement in natural language. It has numeric, parametric, dimensional, and unit values, all of which must be satisfied. It may also contain a sense of direction, that is, an order of operation, and it may contain a sense of dependence and independence, depending upon the context. Mathematically, an equation may be reorganized in a number of equivalent ways. However, in science a particular choice of the expression may be strongly suggestive of symmetry, equilibrium, equivalence, dependence, flow, or computation. The field grows by orders of magnitude when one throws vectors, matrices, and tensors into the pot. The scope of all these possibilities is beyond this Strategy for Science Literacy, and may even be too pedantic and abstract for K-12 education. Nonetheless, the parametric, dimensional, and unit values of equations need emphasis over the mathematical value in the early years. This builds on the idea that algebraic abstractions are parametric and not just number representations.

The preferred technique of instruction and presentation frees equations of standardization conventions without lessening the values of those conventions in any way. It permits the mixing of units freely from different systems, much as life actually presents problems. The method provides insight into the source and use of physical constants. It has intellectual growth potential for such ideas as *dimensional analysis*. This is the derivation of mathematical models based first on the dimensions of the problem parameters and the dimension of the desired solution.

Mastering the skill of algebraically manipulating units enables a citizen to solve many problems in life that should be routine. It helps him avoid many common errors. Proficiency in the art is easy to teach. A few principles are the rules of the game:

1. *Dimensional value.* Equations must balance dimensionally. In other words, a principle of conservation of dimensions applies.

As Einstein said,

$$E\,[ML^2T^{-2}] = m\,[M] * (c\,[LT^{-1}]\,)^2, \qquad (6\text{-}3)$$

which, fortunately for his reputation, balances dimensionally.

2. *Unit value.* Equations, to be complete, need to have units specified or otherwise represented.

In the model above of the load on a calibrated beam with a fish scale, the teacher should instruct the students to practice writing

$$F\,[\text{pounds}] = c * d\,[\text{feet}] * W\,[\text{pounds}] \qquad (6\text{-}4)$$

or alternatively

$$F\,[\text{grams}] = c * d\,[\text{meters}] * W\,[\text{grams}] \qquad (6\text{-}5)$$

From these equations, the student will learn to appreciate that the convenience of having the constant c in the same units as the distance d when the Force and Weight are in the same units.

3. *Conversion factors.* Conversion factors open equations to any system or hybrid system of units, but cannot alter the dimensional balance in any way. They are dimensionless ratios of quantities of units equal to 1. Because they are equal to one, conversion factors may multiply or divide any quantity, in any equation, at any time, and as many times and in as many combinations as desired.

In the example above using Einstein's famous equation, the instructions were to use E in ergs, m in grams, and c in meters per second. These are a consistent set of units because an erg is defined as

$$1\ \text{erg} \triangleq \frac{1\ \text{gram - meter}^2}{\text{second}^2} \qquad (6\text{-}6)$$

where the symbol $\triangleq$ means "equal by definition". This definition provides the following conversion factor for Einstein's equation (or any other for that matter):

$$\frac{\text{erg} * \text{second}^2}{\text{gram} * \text{meter}^2} = 1 \qquad (6\text{-}7)$$

The following conversion factor will be more familiar for the K-12 student:

$$\frac{4\ \text{quarts}}{1\ \text{gallon}} = 1 \qquad (6\text{-}8)$$

The classical definition of the gram provides the density of water at 4^oC:

$$\frac{1\ \text{gram}}{1\ \text{cm}^3\ H_2O} = 1 \qquad (6\text{-}9)$$

Ask students to show that

$$\frac{1\ \text{poise-acre}}{\text{horsepower}} = 7.26 \qquad (6\text{-}10)$$

4. *Angles.* A special caution on angles: Angles are strictly speaking dimensionless quantities, representing ratios between the distances of arcs and radii. Equations including angles require unusual care.

The radian is the angle made by a segment of a circle whose arc is equal to the radius. There are Π (3.14159 ...) radians in a circle. A degree is one 360th of the angle made by a full circle. In physics, the drill is, "Watch out for multiples of Π!" To make matters worse, physicists invented the rationalized MKS system to make a 4Π adjustment in some of the physical constants.

To avoid potential problems with angles, carry one of the artificial units of degrees (degs) and radians (rads) throughout the manipulation. The conversion factor is

$$\frac{\Pi \text{ rads}}{180 \text{ degs}} = 1 \tag{6-11}$$

In the last step, the notation of rads is optional.

5. *Algebra of Units.* Manipulate units as any other algebraic entities. Add like quantities and apply a law of cancellation.

Use this process to solve each equations. and to develop compound conversion factors.

For example, the density of pure water in U. S. or British units at 4oC is

$$1 = \frac{1 \text{ gram}}{1 \text{ cm}^3 \text{ H}_2\text{O}} * \frac{1 \text{ pound}}{453.59237 \text{ gram}} * \left(\frac{2.54 \text{ cm}}{1 \text{ in}} * \frac{12 \text{ in}}{1 \text{ ft}}\right)^3$$

$$= \frac{1 \cancel{\text{gram}}}{1 \cancel{\text{cm}^3} \text{ H}_2\text{O}} * \frac{1 \text{ pound}}{453.59237 \cancel{\text{gram}}} * \left(\frac{2.54 \cancel{\text{cm}}}{1 \cancel{\text{in}}} * \frac{12 \cancel{\text{in}}}{1 \text{ ft}}\right)^3$$

$$= 62.427961 \frac{\text{pounds}}{\text{ft}^3 \text{ H}_2\text{O}} \tag{6-12}$$

For practice, exercise students in making conversions of standard kitchen measures and determining the number of seconds in a century.

Computers have changed the importance and purpose of learning to manipulate units by hand. In software, the state-of-the-art today is that units and numbers are independent entities and that manipulations are arithmetic, not algebraic. Consequently, the programmer and the user must each assure that the unit system is proper and consistent, and that all numbers input are appropriate to the units assumed. Computers have suppressed the necessity of writing equations in a particular, disciplined format, while raising the chances of dimensional or unit errors. Mastery of units is more important than ever for computation, and as important as ever for understanding equations, mathematical models, and physical constants.

More on Graphs

Here are some additional ideas for classroom graphics.

> Make graphs of student progress, showing the cumulative score for homework, tests, and participation. Progress and slope should be most apparent without explanation! Expect the method to have a much more motivating effect than mid-term and end-of-term grades.
>
> Make graphs of plant growth in a window box. These graphs will begin to give some insight into asymptotic behavior as growth begins to limit.
>
> Graphs some hometown basketball or baseball teams win/loss record. For the abscissa, use the game number. For the ordinate, start at zero and increment one for each win and decrement one for each loss. The students will become familiar with a new graphical technique and with a certain type of random process usually introduced in upper division college.
>
> Measure the air temperature inside the room and outdoors periodically and graph. Continue the process throughout the year. Many interesting questions arise from the graph. If the room is not under automatic temperature control, the insulation effects of the building will appear as a lag in the temperature readings. Weather effects will become evident. Students can become more aware of their environment in an active way.

More on Probability

> Assign students to groups and activities by number wheels. Use biased wheels, weighted and skewed, to demonstration an appreciation of how unfairness might arise.
>
> Use sequential wheels to demonstrate conditional experiments. That is, use one number wheel to choose another.

Bean jars and dice can be handy instructional toys. A child can quickly develop an intuition about probability distributions with a bean jar. Colored jelly beans distributed differently in several jars and randomly selected will invite the young brain to compute probability from a probability distribution. Children favor some colors; for example, the greens might go last. The choice is obvious when the jars are transparent. Later, the jars could be opaque, but with the histogram of the distribution shown on the front. Now the child will develop the ability to make an abstraction from the real world to a representation.

Chaos

Chaos has come into vogue in the past few years as an engineering and mathematics art form if not discipline. It deals with the search for patterns in the highly erratic, often destructive behavior of non-linear systems. Followers credit French mathematician Poincaré with noting that these systems exhibit extraordinary sensitivity to their initial conditions. This fact frustrates the ability of models to predict the fine structure of chaotic behavior. Consequently, one often hears the systems referred to in terms like "wildly unpredictable".

The phenomena that chaos studies are not new. Examples derive from many technical fields, such as

- turbulent fluid flow, as in
  - rivers, aerodynamics, convection, and boiling
- certain disease processes, like
  - tremors, Parkinson's disease, epilepsy, stuttering, and cardiac fibrillation
- weather modeling

Some semantic issues need clarifying for pedagogical accuracy:

1. All real systems are non-linear.

A linear system is a mathematical idealization, valid in a region of exposure and operation. A practical definition of a non-linear system might be one which has no useful linear approximation. Orbital mechanics and turbulent flow are excellent examples.

2. Unpredictability is not a scientific term, nor is the phrase "completely random".

Prediction can be coarse, as in climate forecasting, contrasted with finer detail required of weather forecasting. All scientific models strip known patterns from the processes represented, leaving noise of no known predictive value. The model for thermal noise in an electrical resistor is random, and is quite amenable to statistical characterization. It is a close model for radio static and TV snow. Shannon's Information Theory applies the mathematical function of entropy to random processes as a measure of randomness. A discrete process can have maximum entropy in one coordinate system, but not in another. And, the choice of the coordinate system is strictly for mathematical or modeling convenience.

3. Linear systems can exhibit divergent behavior, leading to destruction.

Sometimes linear systems are resonant, meaning that they exhibit increasing oscillations when driven by a force with energy in the resonant band of frequencies. Engineers will call these systems *tuned*. The resulting behavior is one form of instability, called *divergent* behavior. The Tacoma Narrows Bridge discussed earlier is a classic case familiar to all structural and civil engineers, and aerodynamicists. A common example is an automobile with bad shock absorbers. Driven on a washboard road at the right speed, a car in this condition might be unsteerable. Yet another example is an aircraft autopilot badly out of adjustment. The condition can cause the aircraft to be uncontrollable after a sharp jolt of turbulence. In either instance, the resulting vibrations may become so intense that it inflicts structural damage on the system. Long before this happens, the system changes characteristics. Presumptions about its rigidity or elasticity no longer apply as the system becomes plastic or brittle. The linear models for these systems become invalid under such forces. The physical model becomes non-linear.

A system that is unstable need not exhibit runaway or divergent behavior. By definition, instability includes the behavior of a system that oscillates endlessly. With this distinction in mind, unstable behavior like the tremors of Parkinson's disease might be amenable to a model as an underdamped linear system.

An entertaining treatment of chaos was a feature of a 1989 Nova public television production called, *Strange New Science of Chaos*. It would be valuable for classroom viewing. Not only is it entertaining, but it contains at least three technical errors that should provoke a stimulating discussion and analysis. First, perhaps because the program aims for the public, it lapses into unscientific language like "wildly unpredictable". Yet some of the beautiful patterns of chaos that it shows are themselves predictors of chaotic behavior. The fact that a system has attractors, or points of focus in its behavior, constitutes a basis for prediction of behavior.

Second, this Nova program purports to show "the Earth rise seen from the moon with a man's feet firmly planted on it." The accompanying video is a concocted sequence of still photographs of the earth climbing over the lunar horizon. This never happens. The Earth is a synchronous satellite of the Moon! This little selenocentric[13] observation is good for an animated discussion in most technical circles.

Semantic arguments notwithstanding, though, an astronaut on the Moon would see the Earth quite fixed in the sky. This issue challenges the mind at all stages of development, and invites the student to explore the varied and timely field of

[13]*Selenocentric*: moon centered. The notion that the Moon is a satellite of the Earth is so strong that many can't accept the change in reference. The word satellite is actually reserved for the smaller body orbiting the larger.

the lunar theory. This theory is rich in models and approaches abandoned and rediscovered, influenced by space exploration and modern technology. It is still open for improvements.

Third, the Nova program begins with a demonstration of the Chaos Game. This simple game has much to offer for the classroom in spite of it failing to be what Nova declares it to be. It is not chaos, and it fails to support the narrator's extravagant claim, "The revolutionary idea that a chaotic process can give rise to order is destroying old definitions."

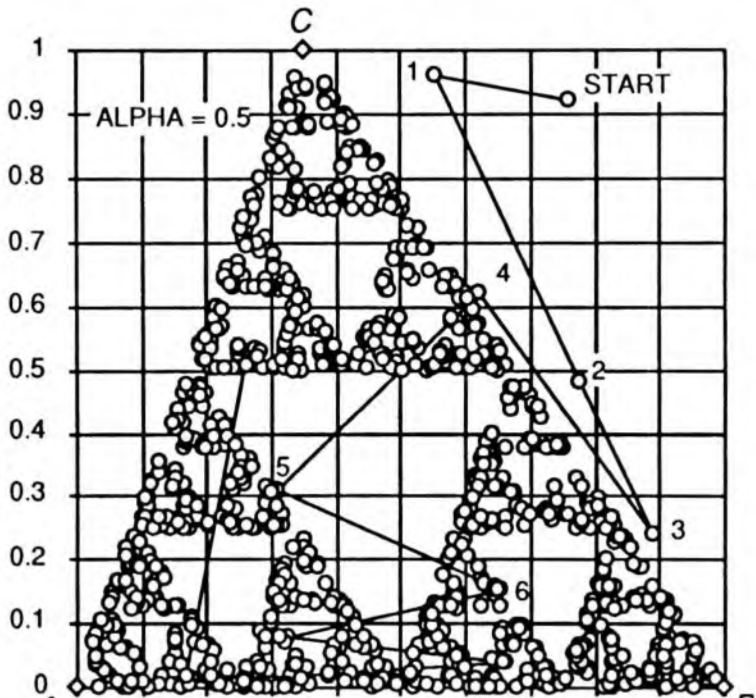
The game is a simple demonstration of a random process that will help the young mind learn to make measurements and to handle randomness. As opposed to a chaotic process, the game is a linear procedure, and it is about as insensitive to its initial conditions as a process can be. It is a good model for demonstrating how a system can be insensitive to its starting point.

The game is suitable in the earliest years for graphics and randomness training. It will help with measurements training, showing the effects of resolution, measurement accuracy, and significant figures. The game helps illustrate the binary number system in the demonstration that each triangular cluster is unique! Much later, it can illustrate many algebraic concepts, like linearity, convergence, geometric or exponential decay, and aliasing.

The Chaos Game has value as an aid in geometry. It is extendible to higher order plane figures, like quadrilaterals, five sided figures, and so on. Students will benefit by determining the scaling criterion necessary to reveal the pattern. Advanced students would also gain by programming the game on personal computers.

To play the game, prepare a large sheet of paper, a felt pen, a ruler, and a die. A spinner with three equal segments is a fine die simulator. Place three points, A, B, and C, widely spaced on the paper, defining a triangle that approximately fills the page. Mark the three points with two die outcomes each, as in (1,2) goes with A, (3,4) with B, and (5,6) with C.

The rules of the Chaos Game engineers and mathematicians call the *algorithm*. It proceeds as follows. Pick a starting point anywhere on (or even off) the paper. The method for the first step is about the equivalent of "pin the tail on the donkey". On the next diagram, it is labeled "START". The second step is to throw the die to select one of the three points on the triangle. For example, suppose the first roll is a 5 or 6, selecting point C. Now, mark a point midway between the starting point and the randomly selected point C on the



NOVA'S CHAOS GAME

Figure 6-14

triangle. This point is labeled 1 on the chart. Use this new point as the new starting point, and repeat the process ad nauseam. That is all there is to it! The diagram shows a computer generated diagram of the process through 1001 points.

Dashed lines connect the initial condition, the starting position, as shown. Dashed lines connect the progress through the first five points. They show that the first die roll selected point C, and the first new position was halfway between Point 0 and Point C. The next die toss selected point B, and so Point 2 is halfway between Point 1 and Point B. The process continues after a long session to the diagram of nested triangles.

Students can experiment with other values for alpha, the scaling factor, and with shapes other than a triangle. The first statement of the algorithm specifies the scaling factor as one half by the word *midway*. If the scaling factor is too large, the figures will become muddied by overlap in what engineers call *aliasing*. What happens by changing the rule of dividing the distance by half? At the top of the next page is a diagram where each point is 60% (alpha = 0.6) of the distance from the present point to the selected apex of the triangle. (The die tossing sequence is unchanged from the initial example with alpha = 0.5.)

At a step size of 50%, the pattern was ambiguous. Is the pattern triangular clusters of points or triangular voids? Taking larger steps makes the pattern quite clear for generalizing the result. Each image of the triangle contains other scaled images in an infinitely self-referencing system that Hofstadter would have liked for his book.

The game's process approximates the analog drawing device called a *pantograph*. Imagine that the drawing showed the sides of the original triangle. Then reproduce each side of the triangle with a pantograph set at 40% (60% reduction). Alternate between the three points of the triangle for the pivot point. Repeat the process a few times, and a continuous version of the Chaos Game will result.

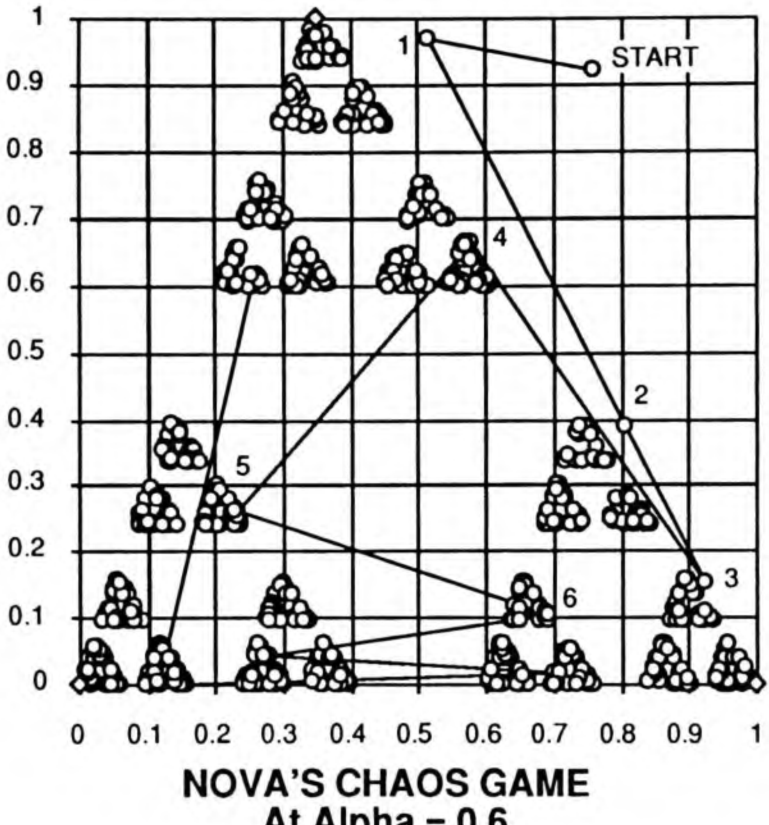
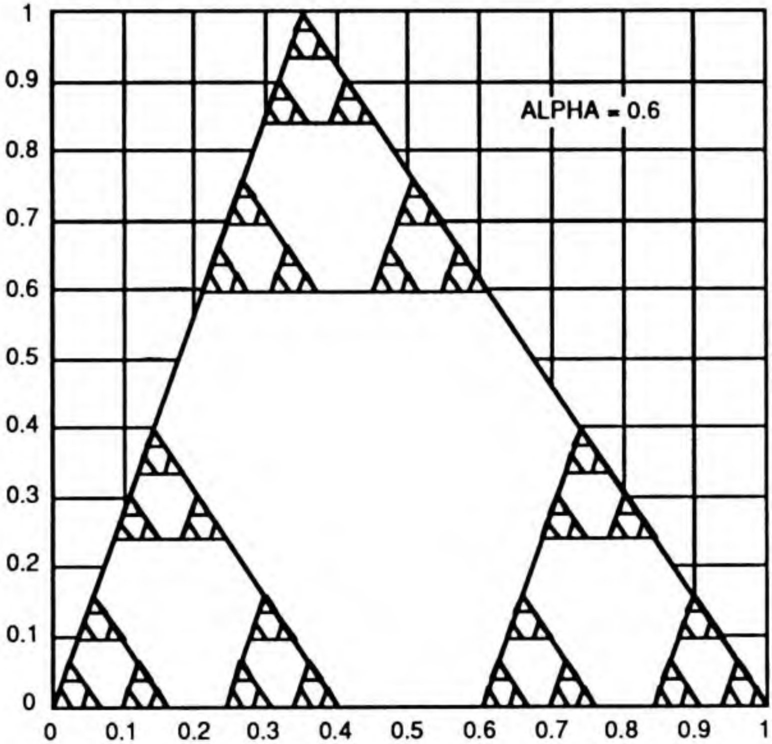


Figure 6-15

The pantograph reproduces a nested set of scaled versions of the original triangle, shown here through five sizes. The pantograph draws reproductions of each side of the triangle each time. Instead of lines, the Chaos Game draws only points, so it is a discrete approximation of the pantograph. The points are close to vertices of the scaled triangles, offset only by the decaying residue of the initial condition! Choosing the initial condition as one of the original vertices, the points of the Chaos Game are exactly vertices of the triangles. Students should calculate how many stages they can



PANTOGRAPH ANALOGY TO NOVA'S CHAOS GAME

Figure 6-16

represent by any of the various methods, pantograph, Chaos Game, simulation, or calculation, before the points become unresolvable or indistinguishable from the corners of the triangles.

More advanced students will be able to show that at each stage of scaling, the Chaos Game selects only one point. The argument proceeds as follows. The number of triangle corners at each level is 3^n, where n is the stage of scaling, beginning at one. So at stage five, for example, there are $3^5 = 243$

vertices, of which the Chaos Game selects exactly one[14]. From this analysis, the students should be able to infer that the Chaos Game never duplicates a point until it runs out of resolution. They should also be able to infer that as similar as any two clusters of points are, they are different.

Advanced students can also calculate how many different outcomes there are to the game. While the chances of two outcomes being the same are extremely remote, the game is highly stable, converging to deterministic patterns.

Another challenge for the advanced students is to replace the linear spacing with non-linear functions and observe the results. This is best done through computer simulation, but it is well within the abilities of a high school student.

C. CREATIVITY

Modeling

Models are creations of man. They serve to communicate objective ideas between people. They are the bridges between basic science and technology. Here are some examples of models from natural science:

ALGEBRA	ATMOSPHERE	ATOMS
BIG BANG	BLACK HOLES	THE BRAIN
CALCULUS	COLD DARK MATTER COSMOLOGY	COMPUTER SIMULATIONS

[14]Hint. Place the triangle points at (0,0), (0,1), and (1,0), and set the initial condition at the origin. Use the scale factor of one half, and represent the point coordinates in binary! Each one that the die selects is right shifted at each successive role, creating a unique new number.

DNA	EARTH QUAKES	ECOSPHERE CYCLES (Energy, Nitrogen, Oxygen, Phosphorus, Sulfur, Water)
EQUATIONS	EPIDEMIOLOGY OF AIDS	EVOLUTION
GALAXIES	GEOMETRY	GLOBAL CLIMATE MODEL
HEREDITY	MOLECULES	OCEAN CURRENTS
PLANETS	PLATE TECTONICS	QUARKS
QUASARS	REACTIONS	SCALE MODELS
SENSES & PERCEPTION	STARS & SUN	STEADY STATE COSMOLOGY
SUBATOMIC FORCES, PARTICLES, ENERGY	VOLCANOES	

To the extent that a model describes an entity or a process, it is a generalization that extracts the repetitive part of the measurements. Modeling entails the separation of patterns and relations from noise. Among all man's endeavors, discovering patterns and revealing them is unique in its creative challenge.

Science hypothesizes that patterns extracted from past data will hold in the future. If a model relates only to statistical correlations, its quality is limited. This is true even when the relations persist into the future. Instead, the principal value of statistical correlation to a scientist often is as a pointer to Cause.

A law of mathematics says that given enough independent variables, a model will fit an arbitrarily complex set of data. Moreover, the data supporting a model need have nothing whatsoever to do with the thing represented. Yet the modeler can come ever closer to the historical data. He can always find a set of linear equations to cause a long sequence of dice throws to match recent stock market performance.

So science values more highly the model with the least number of assumptions and the least number of independent variables. This preference is not just for the esthetics of elegance, but for the greater strength of the model. The fewer the number of variables required in a model and the wider the range of predictions, the greater is the sense of having discovered Cause and Effect.

The message is the same for the K-12 student of science, for the juror interpreting expert testimony on a technical issue, or for the citizen trying to understand the risk in exposure to a chemical: the core of science lies in models created to represent the Real World. The first impediment to this message is semantic. The word *model* is likely to create the mental image of a physical scale model, like a model airplane. The word applies in a much larger sense.

Physical Models. The model airplane is a way of describing the airplane that it represents. It might be a toy, or it can be a sophisticated scientific model. Model airplanes have regular use in science and technology, as in measuring radar reflections, measuring aerodynamic forces in a wind tunnel, fitting new aircraft onto airfields and into terminals, outfitting aircraft with seats and communication systems, and so on.

Models in science are simply descriptions of entities or processes in the real world. A model can be a physical object, like the model airplane, or like a wooden representation of a DNA molecule, a geological mockup of the Pacific Plate, a computer program, or an abstract set of equations.

Prose Models. A model is often a word description like evolution, or Newton's law of action and reaction. Today everyone takes for granted mass and the particulate nature of subatomic bundles of energy, going so far as to call them particles. Both mass and subatomic particles are manmade properties. They are models, and in these cases models that work so well that have become universally accepted into the language. Usually prose models imply other relationships that are suitable for abstraction and representation in equations as math models.

Mathematical Models. Most models are mathematical in some form. Examples include a formula like gravitational attraction, the energy in chemical bonds, a computer program like one of the Global Climate Models, or a simple curve fitted to stock market data.

A model can be as subtle as expressing the relationship between a phenomenon and a parameter. A prediction can be as simple as showing that this relationship is present in a different setting. For example, Newton's model of gravitation says that the attractive force between two bodies diminishes as the square of the distance between them. An elementary prediction follows that doubling the distance between an object and the center of the earth will reduce its weight by one fourth.

The college text book *Biology* (C90) presents the results of demographic math modeling, but without any derivations. The text misses the opportunity to show students that math models express relationships implied by natural language. Each math model extrapolates from a prose model, employing pure reasoning and empirical evidence. Instead, the text errs by saying

> As we discussed [earlier], it is often difficult for ecologists to apply experimental methods to their questions and to predict the consequences of changes in ecological systems. Mathematical modeling, to the extent that it is based on accurate assumptions, provides an alternative approach to some of these problems. It allows an ecologist to study how variables interact or to make predictions about what would happen if some of the variables change. Particularly in population ecology, which deals mainly with variations in numbers and rates, mathematical modeling is a

> common method. This approach itself can be complex. (C90) Pp. 1080-1

This paragraph casts mathematical modeling as a weak substitute for direct experimental methods, to be used perhaps when access to the natural processes is impractical. In science, the mathematical model is not something selected from a catalog or handbook of functions. It is the ultimate abstraction of the very language used to express scientific models of the Real World.

A student reasonably could infer from this quote that mathematical models are more susceptible to inaccurate assumptions than other types of models. Exactly the opposite is true. Questionable assumptions in all fields are routinely surfaced by mathematical modeling.

Biology speaks of selection coefficients in population modeling, saying that they

> are only statistical estimates, something like a handicapper predicting the order of finish for a horse race that has not yet begun. (C90) P. 452.

Statistics underlie measurements, scientific models, the power of science, and nature itself. No scientist can call himself qualified if he fails to understand the statistics and random behavior in his field. By the teaching cited above from *Biology*, Mendelian heredity would be a pastime for a race track tout. Yet the distribution of genetic material in inheritance is one of the most challenging phenomena in major philosophical questions, like

> Does randomness, and hence entropy, really exist in nature?
>
> Does every Effect have a Cause? Is everything part of an infinite series of causes and effects, or is there an ultimate Cause?
>
> Is every Cause ultimately knowable?
>
> Is randomness simply a measure of man's ignorance?

Educators need to teach that science uses mathematical modeling at every opportunity. A mathematical model is rarely a separate model, but is an abstraction of another type of model implied by logic and definitions. Mathematical analysis of populations produces more than quantitative facts about the size and composition of colonies, as suggested in the citations. It provides great insight into qualitative factors like the theory of evolution itself.

For a detailed example of math modeling, see Appendix C: Biology Mathematics. Here is an elementary example suitable for a properly prepared high school student. The model shown may be non-standard, for the idea is to stress how math modeling flows from the natural language of model statements.

> Step 1: Observation. A biology student believes subjectively that families are rather small in the U. S. How small are they? That is, how can he make this observation objective? If he had measurements, what might he conclude about the population size?
>
> Step 2: Measurements: The biology student samples households in his area, finding that the average family consists of two parents and, say, 2.15 children. With the help of the local library and the county's board of health, he also acquires statistics of life expectancy. From these data, he estimates that 97%[15] of children will become parents themselves and that the average age of a new parent is 20 years.
>
> Suppose these data held in the following way: An average couple has 2.15 * 0.97 = 2.09 children who

[15]The figure of 97% is almost certainly too high for the United States. For the exercise, a large number allows the student to analyze growing rather than shrinking populations. The exercise is easily repeated for smaller numbers, and the student can determine what the threshold reproduction rate would be that divides increasing and decreasing populations.

will become parents, and an average generation is 20 years. This would result in 1.045 offspring/person/generation.

3. Math Model: How fast would the population grow if the measured relation held for the entire population? The biology student begins by introducing some symbols to prevent writer's cramp and to save paper. Moreover, he finds that by writing out each relationship in longhand he can't write fast enough to keep up with his thoughts.

Let S stand for the Size of a generation in terms of the number of individuals. Use a subscript to indicate the generation to which S refers. So S_0 is the size of the present generation, and S_1 is the size one generation later. The data of the measurements indicate that

$$S_1 = 1.045 * S_0. \qquad (6\text{-}13)$$

This formula suggests that another symbol would help. He assigns r to the ratio of the number of offspring per person per generation. So

$$S_1 = rS_0. \qquad (6\text{-}14)$$

From this he uses elementary techniques to show that

$$S_n = r^n * S_0. \qquad (6\text{-}15)$$

Using a cheap electronic calculator, he can show that if the rate is 1.045 then the size will double in just under 16 generations.

Because of the form of his data, the result refers to the size of each generation, not the size of the population. If he knew how long an average generation lived, he might be able to estimate the population growth rate. He lets $P_n(k)$ be the total population alive during the n^{th} generation, going back a total of k surviving generations:

$$P_n(k) = S_n + S_{n-1} + S_{n-2} + \ldots + S_{n-k+1} \quad (6\text{-}16)$$

A little algebra leads him along the following path:

$$P_n(k) = S_n*(1+r^{-1}+r^{-2}+ \ldots +r^{-k+1}) \quad (6\text{-}17)$$

At this point, he can already see that when the size of the generation doubles, so will the size of the population! This happens because the long expression in parenthesis does not depend on the generation index, n. Calling a little more on his high school algebra, he can reduce this last equation one more step, yielding

$$P_n(k) = S_n*\left(\frac{1-r^{-k}}{1-r^{-1}}\right) \quad (6\text{-}18)$$

While his derivation works for integers, if he is in an AE class, he might research some college texts to show that the result is valid for real numbers as well as integers.

Our student biologist has enough information to keep him busy for a semester. He can relate population size to generation size.

4: Prediction & Validation. His model predicts a certain rate for population growth. He can confirm this prediction with more data, seeking validation of his model. He can vary the parameters in his measurements to see how sensitive the result is to the data, measuring the difference between facts and his model's predictions.

A math model is not something a scientist chooses from a general mathematics catalog and auditions with his data. In technology, this has the disparaging name of Cook Book Engineering. It exposes the investigator's lack of appreciation for the subject matter and for Science.

A mathematical model extends statements in natural language. Mathematics shows the logical consequences of statable relationships and principles. It is not a surrogate field of study employed when experimenting on the Real World is not feasible. Any statement about the Real World reducible to abstraction and mathematical relations should undergo mathematical analysis as a matter of minimum scientific standards.

Objectives for Models. A scientific model has two principal goals deeply intertwined and rich with subjective overtones. First, models serve to explain the Real World to man, and second, they predict what the Real World has in store for him. However, science permits itself no subjective content; objectivity alone provides science it power. Objectivity permits science to combine the brain power of the whole community of people who now practice or who have ever practiced scientific arts, achieving knowledge far beyond any individual's capacity.

Science is firmly connected to the Real World by way of two rules:

1. Scientists create models from real data, or by reasoning from real data.
2. Models must admit validation through verification of their predictions of new data.

So the objective of scientific modeling is to create generalizing and unifying descriptions that define and incorporate all relevant data, and that predict results for future experiments. This is the setting of hypothesis and theories.

Real Data Domain. Scientific models must first span all available data. Second, they must fit those data to a quantifiable level of accuracy. A model need not be universal, but instead must define the domain over which it claims validity.

Further, science does not allow appeals to non-scientific entities or processes. That is, unmeasurable things are inadmissible in the models. These restrictions to data and only data compel scientific models to operate on the objective world.

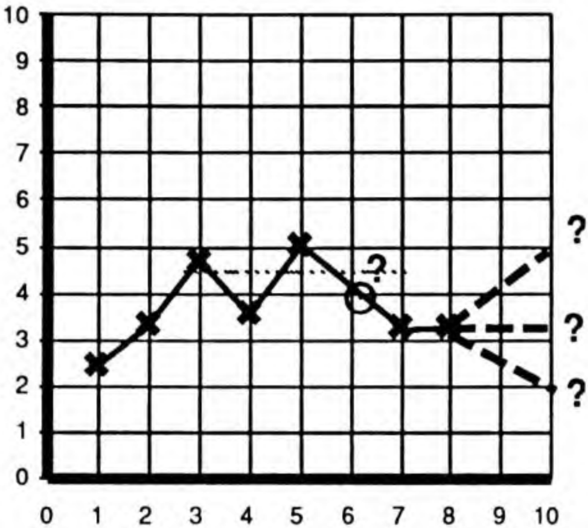
Excluding data beyond that specified by the model is impermissible. A scientist would violate the rules of scientific method if he were to pose a model which was silent about known data. Similarly, he cannot escape falsification by being selective outside the model about the data.

The practice of ignoring data occurs frequently in non-scientific pursuits, and it is pure fraud. Many years ago, an enterprising individual sent predictions on the outcome of a major sporting event to thousands of individuals. Half received the prediction that one team would win, and the remainder he told the other team would win. After the event, our hero sent those with the correct prediction another prediction about a major election. Half he told that one party would prevail; half he told that the other party would win. To those with the correct prediction, he sent yet another prediction. After several more steps, he offered one more prediction for sale. Postal authorities promptly arrested him for mail fraud.

Preselection of data is what links dog barking to earthquakes. It may underlie the claims about extremely low frequency (ELF) electric fields correlating with childhood cancer.

Elementary Graphical Model. The simple two dimensional graphs introduced in the last chapters lead immediately to the most essential and elementary principles of model making.

A plotting procedure discussed in the last chapter was the follow-the-dots strategy. Remember a plot is called a *curve*, whether it consists of smooth arcs or not. The simple connection of data in a curve allows one to read values between data points. This is *interpolation*. If the curve extends beyond the domain, then it permits estimating data points in the future. This is *extrapolation*.



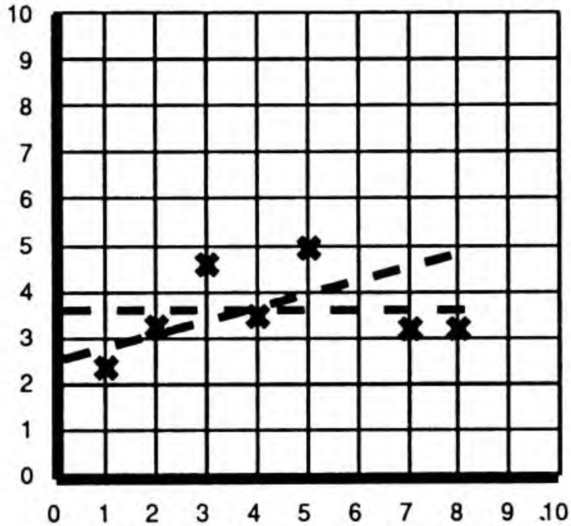
FOLLOW-THE-DOTS PSEUDO MODEL

Figure 6-17

A follow-the-dots strategy has little real power for interpolation and none for extrapolation. So it earns the name here of *Pseudomodel.*

The only data points used in the follow-the-dots interpolation are those immediately surrounding the point of interest. Other data points make no contribution to the accuracy, knowledge, or representation of the curve at that point. The value of this curve at x = 6 is 4. Other ways to represent this particular point are Y(6) = 4 and (4,6). Now the value at x = 6 depends only on the two adjacent values, Y(5) and Y(7). Changing any other points at x = 1, 2, 3, 4, or 8 have no effect on the curve connecting the points at 5, 6, and 7. A translation of this effect is that no further knowledge of either the past or the future contributes to the estimate of the missing value at x = 6. Such relationships exist approximately in nature, but the scientist must consume a great deal of data to establish that it might be true. Furthermore, the curve has no direction beyond the last data point, (8,3.2). Therefore, the curve has no predictive power. It is not a model outside of the region between x = 1 and x = 8, indicated conventionally by [1,8]. Between any two points, the Follow-the-Dots Pseudomodel is a weak first order model.

Most graphical strategies imply some model. This next figure contains a zero order model and a first order model:



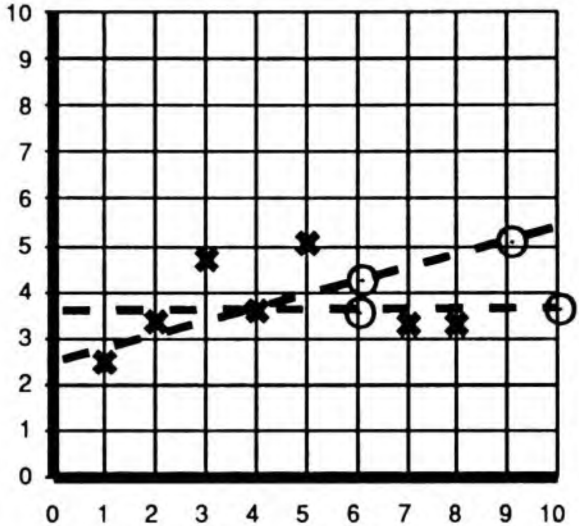
ZERO & FIRST ORDER MODELS

Figure 6-18

The horizontal line is the zero order model. It represents the average of the data, plus or minus some constant bias.

The sloping line is a first order model, fit with unknown criteria. Various mathematical measures are available to assess how well curves fit their domain of data. Least sum square error is the most common, where the name is highly descriptive. The model parameters are those that make the sum of the squares of the errors a minimum. Curve fitting techniques cause every data point to influence the parameters of the model. This was not true of the Follow-the-Dots Pseudomodel. Nonetheless, the value of any model is in its predictive power in the range, not its goodness of fit in the domain.

The two curves above fit the data represented by the set {x | 1-5,7-8}, which constitutes the domain. The curves contain interpolative and predictive capabilities, as shown in the next figure.



INTERPOLATING AND EXTRAPOLATING

Figure 6-19

The chart shows one point of interpolation and one point of extrapolation for each of the two curves. These two points are a part of the unlimited range of the model.

The assumptions of zero order and first order are strictly hypotheses. To the extent that they hold over the domain, the curves provide predictions. The two models above are linear, the simplest imaginable. They would suffice if the granularity produces the needed results. They also will do if the experimenter is not seeking more insight into underlying processes.

Here is a simple example of a nonlinear process for young students.

> Place a wooden right-circular cylinder in a large container which also is a right circular cylinder. (Put a heavy dowel in a tin can!) Fill the container with water, measuring the height of water in the container. Plot the height of the water as the ordinate against the amount of water added as the abscissa. Continue beyond the point where the wood cylinder floats. Draw a curve fitted to the data. It will be continuous, consisting of two linear segments broken at the point where the block began to float.
>
> What is the relationship to Archimedes principle?

Granularity is another important concept in modeling, equivalent to scale in a sense. Man may never be able to predict weather in our lifetimes, but he might predict climate. Astronomers working on the galactic scale are measuring matter as much as physicists exploring subatomic particles. Spanning the massive to the massless, the macroscopic to the microscopic, is far beyond the models of science. At many levels of granularity one will find distinct domains of research, with different vocabularies, different units, different tools, and much different equations.

Models within Models

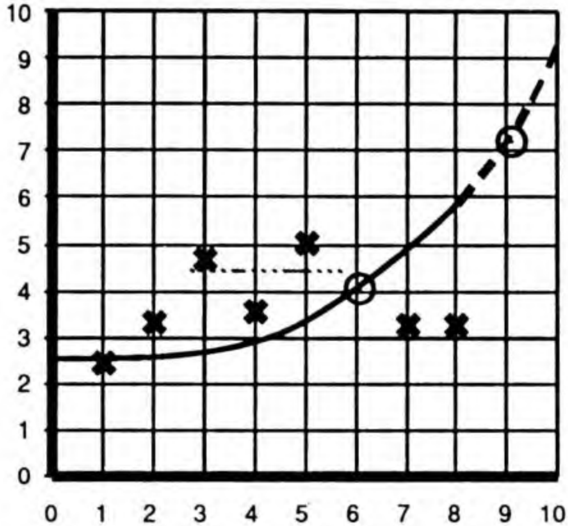
Hofstadter's (H89) work discusses models in which the different layers are independent. He illustrates this with words written with letters where each letter is itself a composition of words written in a much smaller type font. This is independent layering. Science has no reason to suspect such a composition in the Real World. One philosophical school believes that the behavior of the universe is somehow dependent on the behavior of the smallest imaginable particle. So it might be with man's brain — from the behavior of electrons in neural matter, through the structure of the neuron and its interconnections, and into the incredibly complex structure of thought, perception, and the hierarchical control of the brain itself!

Scientists frequently deal with models at different scales, usually for sheer efficiency in handling the information. Physics provides obvious examples because it deals with models from the subatomic to cosmic. Engineers do the same when they model complex systems, except that in systems the models must all operate accurately and simultaneously. They achieve this effect by minimizing energy flow from layer to layer. In this way, sub-layers have little effect on the parent process. This is rather analogous to the strategic planning process, where the strategy partitions and uncouples the underlying philosophy from the practice of science.

The problem of understanding in the face of complexity becomes manageable through partitioning and choosing the proper scale for observation and measurement. Man's software models exhibit this same kind of layering. It may be highly artificial. Scientists extract models from descriptions of the Real World at a certain level of magnification, resolution and approximation. They know that the models have boundary conditions dependent on things outside the model, but they do what they can with what they have to keep the whole manageable.

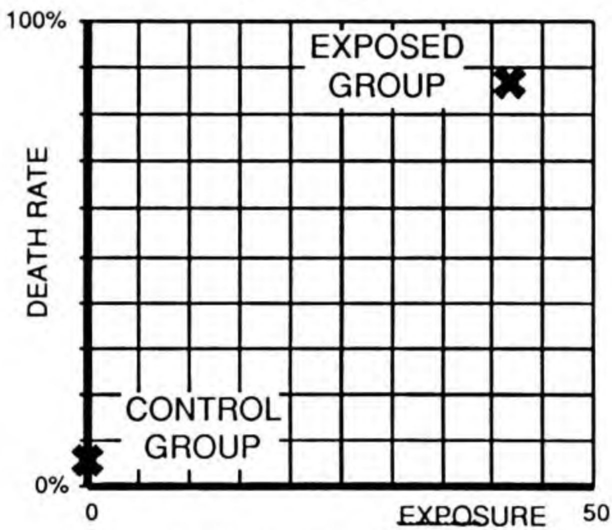
The scientist might reason that other laws hold, so that a curve must have certain characteristics. For example, his model might look like the graph at the top of the next page. Here, the solid curve is the fitted section, and the dashed curve is the extrapolation. The following example should illustrate the importance of knowledge of the underlying law in model building. The example is whimsical, but the application is quite real.

Suppose a scientist wants to estimate the effects of exposure to a hazard. However, he finds that at the usual exposure levels, the response rate is so small that experiment is inordinately protracted or expensive. The standard technique is to expose a group to a much larger dosage, and interpolate to expected levels. The data will look much like the second chart on the right.



HIGHER ORDER MODEL

Figure 6-20

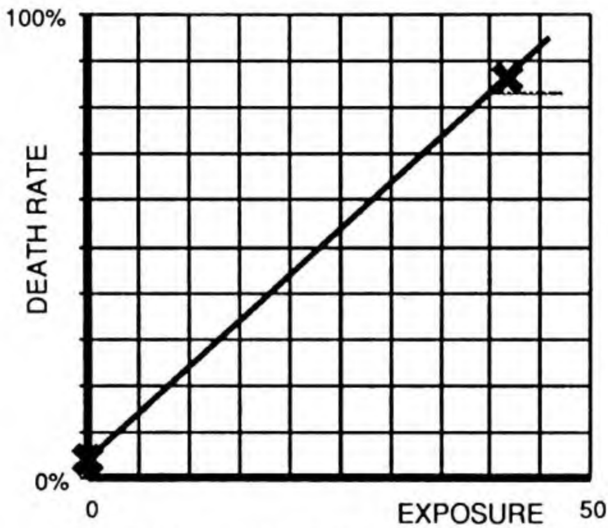


EXPOSURE DATA

Figure 6-21

Presumably, the scientist has a control group, or can rely on other statistics for the datum shown as the control group.

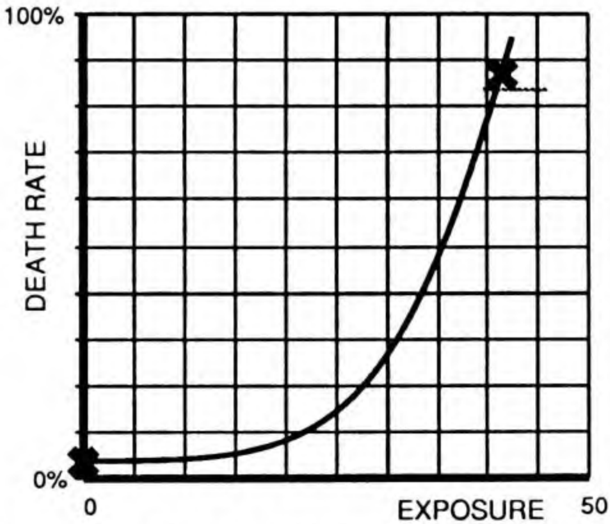
Suppose he wants to estimate the death rate of a fall from a 6" curbstone. He selects some hapless laboratory animal species and exposes animals to falls from the top of his laboratory, 43 feet off the ground! The experiment goes quite quickly, as it kills nearly all the animals in the first exposure. About 3% of the animals die of fright before the drop, elevating the point at zero exposure. Now he plays follow-the-dots which in this case is a linear strategy, producing the following data and model:



FOLLOW-THE-DOTS
EXPOSURE PSEUDO MODEL
Figure 6-22

From this graph, he estimates that the death rate due to a 6" fall is about 5%, or an additional risk of 2% over no exposure!

Why did this experimenter choose this linear model? It is so arbitrary a decision that it demands justification. A more reasonable curve would have a non-linear shape. The shape suggested by the following graph is one that occurs repeatedly in science:

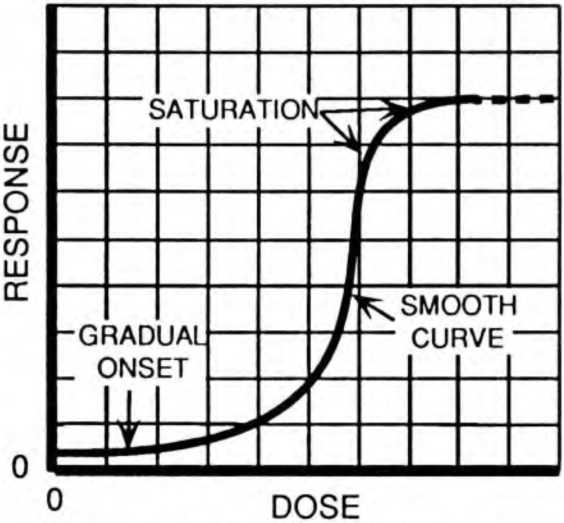


NON-LINEAR EXPOSURE MODEL
Figure 6-23

For a wide variety of curve shapes, the additional risk near zero is not measurable.

Although the previous example is a bit morbid, it has the advantage that the critique sits well with everyone's intuition. The injury suffered in a fall is not directly proportional to the height of the fall. As a rule, risk is not proportional to exposure.

A well planned experiment would assess the degree of the model as well as determine the data points. A complete dose-response curve would likely show gradual, almost imperceptible onset near zero, and saturation at some high dose level. In between, the curve might reasonably rise continuously and smoothly. The combination of these factors results in a curve as shown in this next figure:

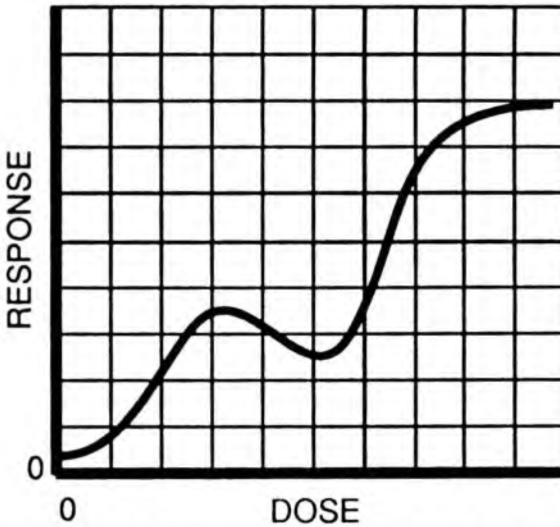


ANTICIPATED SHAPE OF EXPOSURE MODEL
Figure 6-24

This is the shape of a probability distribution, required by Probability Theory. All probability distributions must range between zero and one (100%), and can never decrease from left to right. That is, they can never have a negative slope.

A response curve might not qualify as a probability distribution. For example, conceivably it could have multiple peaks, as depicted in the next figure at the top of the page on the right. This kind of *bimodal* response is anomalous behavior, but certainly not excluded by science. It suggests that multiple causative agents are at work in the process.

A response is not strictly speaking a probability distribution. When it is interpretable as a probability parameter, this may be exactly the underlying law sought by the scientist. A supported, underlying law is what scientists and students should expect. It is what the public should expect and the press demand in responsible studies on pollution and



BIMODAL EXPOSURE MODEL
Figure 6-25

chemical exposure. Anything less rates as no more than a hypothesis.

D. VALIDATION

Science demands validation of its models. Validation is the ultimate process of demonstrating the predictions of scientific models, or falsifying the models on the basis of their consequences. As the famous British philosopher and teacher of scientific method Sir Karl Popper discovered, endless repetitions of past experiences is unsatisfying. Validation consists of devising experiments, gathering confirming or denying data, and subjectively evaluating the model. The predictive value of a model includes a measure of accuracy in the prediction, though not the utility of the prediction.

In the philosophy of science, today's ideas about validation are due to Popper. He laid down his Falsification Criterion to rectify the view of the Logical Positivists that inductive scientific propositions gain greater weight by the accumulation of confirming observations. An inductive proposition is one which generalizes from Real World data to all similar situations. Our language allows us to express a proposition as universally quantified. For example, "Each human has unique DNA." (which is false because of identical siblings). Another form is the implied universal quantification, as in "Real processes are irreversible." (which is true, so far). The falsification principle mandates that significant, testable hypotheses be cast from scientific models.

The terminology here is consistent with Popper's views. A fresh instance of data which is part of the basis for the generalization is weakly confirming, contributing to a larger and generally more accurate data base for the model. A prediction, though, is a Popperian hypothesis. It lies outside the domain of the model.

However, the imperative that models must predict is not a casual preference for one form over another. It is more than simply philosophical or metaphysical prerequisites. It is strongly analogous to the mathematical theorem discussed above, namely,

> Given enough degrees of freedom, a mathematical model can be made to fit any finite data set.

A model has a number of degrees of freedom. An economical model will have many fewer degrees of freedom than the data, also known sometimes as the *training set*, that it fits. And so, the more economical the model, the stronger it is mathematically. The training set must not be the used for judging goodness of fit.

The Method allows a scientist to hold data in reserve when he formulates his model. However, he must keep those data as unknowns to the model. This is an ethical imperative when he discloses the model to the public. After he forms his model, he may use the reserved data to test its predictive power. If he adjusts his model to work better with the reserved data, he must again test his model against an unknown data set. In this sense, prediction need not be only for the future in the

Real World. It need be only the future as far as the model knows.

An instance of validation often becomes a part of the domain of the model in a larger context. If the data simply reproduce data already in the domain, they contribute to the accuracy estimate of the supporting data. If the data are unique and still fit the model, the domain of the model increases.

Scientific Method does not mandate some sort of formal validation phase or program. Supporting data for a model will increase from time to time at the convenience of scientists or as opportunities occur in nature. The pool of data increases with the addition of previously unused data or with the collection of new data.

Validation leads to a subjective scoring which must lie outside the realm of science. Even if the prediction has great implications, going far beyond expectations, confirmation may be more due to the small capacity of the total of human intellect in the greater scheme of things than it is to the infallibility of the theory. These are not the properties of falsification, however! A single instance of falsification mandates that the scientist repair his theory or discard it.

Often validation is not as straightforward as these discussions might indicate. It is not as simple as measuring the degree of bending of starlight around the sun. As science advances, scientists create models of phenomena more and more deeply imbedded in noise. As the easy models become part of the history of science, the new models encompass more uncontrollable phenomena that can mask a direct observation of the prediction. This is particularly true in epidemiological studies, including the effects of pollution on the incidence of human diseases or agriculture. It is the rule in ecology problems, including acid rain, deforestation, global warming, and ozone depletion. It is common in communications and detection, as in tracking celestial objects or analyzing the spectrum of radiation from distant objects. The phenomena in cases like these may be imperceptible to the untrained eye, or simply much smaller than variations which might occur due to other causes. The experimental design problem in assessing these phenomena challenges the creative skill of the scientist more than developing the original model. Many models never reach fruition as a theory because of the conceptual problems in designing a method for validation. Nonetheless, many marginal models manage to affect public policy and national well-being far beyond their predictive power. The impact that these flimsy, conjectural models are having is a measure of the prevailing low level of science literacy in America.

Data that fail to fit a model necessitate a redefinition of the model. The model must be altered to restrict its domain from any falsifying data. If the restriction causes the domain to vanish, that is, if no supporting data remain, then the falsification is complete. Of course, long before this has happened, the model will have become too specialized and too narrow for any use.

A current example is the Cold Dark Matter cosmology, called by Scientific American "the leading theory of the Universe" since the early 1980s. Recent analyses of data from satellites show X-ray sources from space in concentrations not predicted by the model. The new data have not yet falsified the model. Instead, the subjective rating of the model receives a demotion as scientists take sides, holding to differing beliefs. Meanwhile, the proponents of Cold Dark Matter return to the drawing board to repair the model.

A corollary of the validation rule is that the model must lead to an unambiguous recipe for communication to others for independent validation.[16] Constructing a validating experiment often requires interpretation, skill, and creativity on the part of the scientist. Science reserves its greatest rewards for the scientist who conceives an especially clever experiment that either validates a new theory of breadth or disproves a well-established one.

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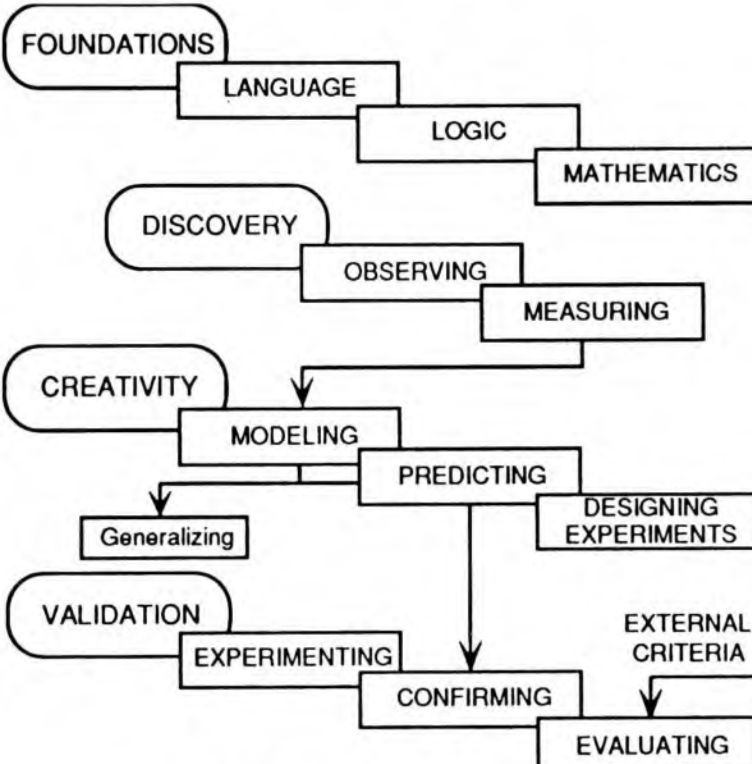
[16]The idea of a recipe is akin to the operational concepts of Nobel Prize Winner P. W. Bridgman.

APPLYING THE SCIENTIFIC METHOD



THE SCIENTIFIC METHOD
Figure 6-26

When an individual understands these simple prerequisites for the Scientific Method, he has a power to judge — to discriminate between knowledge and fiction. The Utah legislators would have been able to see that Cold Fusion was at best a hypothesis, if they'd read *Evolution in Science*. Daily the press carries stories about scientists stepping out of their field to claim knowledge by authority or some other osmosis-like process over

global warming	environmental holocausts
holes in the ozone	extinction of species
nuclear winter	energy exhaustion
landfill saturation	cancer

leukemia & power lines
VDTs[17] & birth defects

and on and on. New items regularly appear on the list of endangerments. The movement is close to exhausting the public, while the excesses in the name of the environment are beginning to take an obvious economic toll. Some of the issues are real and require a measured, reasonable response. This could happen with a public and a media informed on the scientific method.

In the Introduction, the Strategy criticized two media reports for irresponsible coverage of certain technical issues. Now that the Scientific Method is available, here are some examples of how the Strategy suggests that the media cover scientific matters.

Salmonella Outbreak Due to Poultry Products

A reporter assigned to cover the report of an outbreak of Salmonella[18] from chicken products must challenge the source's model. The reporter should interview the source in enough detail to validate the following information about the model:

1. Precisely and unambiguously, what the model is and what it predicts. Without any qualifications, someone is making a sweeping, nationwide connection between chicken products and Salmonella poisoning. Where and when were the data collected?

[17] Video Display Terminals, aka computer screens or displays.

[18] Many bacteria are in the genus Salmonella, which are commonly found in the intestinal tracts of animals. The genus includes S. typhi which causes typhoid fever, but the discussion here is about the more benign species.

2. That the model uses a reasonably complete set of facts. In this case, it should use epidemiological data, perhaps confirmed by the Center for Disease Control or some reputable agency.
3. Assumptions the designer made in creating the model. Specifically, how is the link made between Salmonella poisoning and poultry products?
4. The model reproduces the facts accurately. The model should reflect facts about the incidence of Salmonella. If the model does not reproduce the facts, then the reporter should qualify the model as a conjecture for his readers.
5. The designer has shared the model with the public and received peer review.
6. The model predicts a quantitative danger to the public on a relative or risk-benefit basis. If the prediction is not available, the reporter should characterize the model as no more than a hypothesis.
7. The model has received some validation. If the model has not progressed to this point, the reporter should qualify the model as a theory.

The Department of Health in New Jersey put a new ruling into effect on January 1, 1992, ordering restaurants to serve eggs "well done" only. The ban didn't last three weeks because of the public outcry. In reporting the story, the Los Angles Times account[19] left the reader somewhat confused as to the name of the bacterium and the disease. At one point, the story said that there were 12,916 cases of "Salmonella enteritidis [sic]" reported in the United States between 1985 and 1991, of which 49 were fatal, but gave no source. At another point, the article ranked New Jersey sixth in reported cases of Salmonellosis, which is known as gastroenteritis or simply food poisoning, according to the Center for Disease Control. Still later, the same article said that the Food and

[19] Los Angeles Times, January 23, 1992, p. H42.

Drug Administration (FDA) had banned undercooked eggs at nursing homes, citing the following statistic: between 1975 and 1987, 2.4% of food-borne illnesses in the U. S. were among nursing home residents, but they accounted for 19.4% of deaths. First, one wonders if the reporting years were inclusive. Second, is the higher death rate of 8.1:1 (19.4%/2.4%) in nursing homes rather typical of all diseases in such places? Third, does food-borne disease refer to yet another category of disease? Third, how much different is the incidence of the disease in New Jersey when it ranks sixth in the nation?

Perhaps the New Jersey Health Department was confused by such reporting as well. Putting aside the clumsy statistical reporting, the public health question is: Was either the FDA's or New Jersey's action reasoned and responsible, or were they contributing to the general hysteria and ignorance about food, medicines, and statistics? Is a disease that occurs 13 thousand times in something between five and seven years among 260 million people, which is a rate of about 0.7 per 100,000, with a general fatality rate of less than 0.4% worthy of such measures? For a scientist or a scientist-in-training, there is no answer, but either can certainly throw some light on the subject and the ethical questions.

The problem is that "safe" and its companion "zero tolerance level" are unattainable absolutes, and "safe enough" or "acceptable rates of disease (or death)" are subjective. These considerations place such concepts outside of science. The usual scientific tool in less vital matters is the cost-benefit study, but that is difficult to formulate when the benefit is as trivial and fleeting as the enjoyment of Eggs Benedict, mayonnaise, or Caesar Salad. If the benefit were just industry profit, then only the heartless would weigh that against disease or even one death. The problem is that the public and their officials lack the scientific literacy to understand that there are risks in everything. In a clinical study of "scrubbing up" by surgeons, bacteria counts on hands actually increased after washing!

The problem here is dealing with uncertainty and with the simple discipline of thinking beyond one or two levels of Cause & Effect. No one would tolerate a single egg being shipped randomly to the public if it were known to contain a lethal dose of a poison. And the public health services must be continually alert to concentrated outbreaks as in the infamous Typhoid Mary, who left a trail of death from 1904 to about 1915. But what level of concentration of Salmonella is reasonable, especially when the bacteria is in the general environment anyway? At what level do we call the product tainted?

What happens if the consumption of poultry products drops precipitously because of public panic? One almost certain result is that poultry products will be slower to move from grower to consumer, suggesting that they will remain in cold storage for longer periods. This could directly contribute to an increase in Salmonella concentrations and public disease!

In many parts of the supposedly civilized world, food handling is abysmal by American standards. No well-fed American could bring himself to buy a partially-dressed chicken sold off the floor of a Moscow meat market. An economically poor industry cannot provide the public the protection that Americans have come to expect. On the other hand, a robust industry, concerned as almost all industry is with responsible behavior, provides the best available protection for the public. Products are kept in cold storage at the optimum temperature, with minimum exposure to air, contaminants, and warm temperatures. Designs are underway now to provide even better protection and quality for the public through gamma radiation of foodstuffs. Unfortunately, this well-known method of long-standing for preserving and protecting food is meeting with the same kind hysterical reaction from an illiterate public as brought us the Chilean grape scare and handicapped any other venture in America associated with the word *nuclear*.

Passive Smoking

"Evidence Mounts Against Passive Smoking" said the headline quoted in Chapter 2 about a collection of EPA studies. Epidemiologists might postulate a theory from such evidence that there is a statistical correlation between passive smoking and lung cancer. The model might quantify the following statement,

> "An individual exposed to passive tobacco smoke will have his chances of lung cancer increase by __________ (insert amount)."

That quantification might be in the form of a graph showing the mean incidence of lung cancer as it depends on the lifetime exposure to smoke particulates. Journalists should ask for an unambiguous statement of the model, and for its quantified representation.

Modelers are skating on thin ice if there is no evidence to support their model, but science allows for if not encourages à priori theories as well as à posteriori ones. Lacking confirming data, journalists should report the model as a conjecture. In this case, 18 of 23 studies falsify the generalization, leaving the model awash. The creators need to recast their model in such a way that it excludes all the falsifying studies. Journalists might rank it as a hypothesis once it is exclusive to the foreign countries represented by the five supporting studies. The reporters next should ask the scientists to account for the differences between the U. S. and the foreign data.

The scientist should add other statistical variables to his model to admit all the confirming studies and exclude the others. The mathematical method that does just this is a well-known process called *discriminant analysis*. Whatever the method, once the repair is complete, journalists can rank the model for the public in terms of elegance. If relatively few variables are necessary to make the discrimination, the theory is intuitively (or subjectively) stronger. For example, Exposure to second hand smoke and saturated fat content in the diet might prove sufficient.

suppose, though, that the scientists must restrict their model to data from a narrow geographical area, segregating the studies according to their locale. This same method is suitable for the salmonella poisoning case. When the data points to particular regions for the problem, scientists have a clue in the search for different or contributing causative agents. When new agents remain elusive, continuing the process can get silly. Given enough data points, the incidence of lung cancer will become statistically dependent on the discriminants of zip codes and drivers license numbers.

So scientist may still want to postulate such a complex, inelegant theory, but they should be ready for extra public scrutiny. The suggested ratings are partly subjective, but nonetheless excellent guides for the scientist, the educator, or the journalist. The acid test, so to speak, is, "Does the model have predictive value?"

Science dooms the model linking passive smoking to lung cancer to no more than a hypothesis because it is a weak statistical correlation lacking both Cause & Effect and predictions. It is nothing more than a generalization. Additional confirming studies which might support the presumed correlation pattern only make the founding data more reliable.

of the generalization is correct, proponents need to extract some qualitatively different predictions from it. A clue as to where to look might lie in the different results between U. S. and foreign studies. Perhaps the tobacco curing process is significantly different overseas. Perhaps the model should discriminate between the methods of exposure in the U. S. and overseas. A few leading questions by an inquiring, informed reporter could push the would-be scientists in the right direction.

Elevation of the model to a theory could follow, once studies support it. However, any one study that does not produce the theoretical result, disproves and discredits the theory! The model receives a demotion to a non-theory. The Scientific Method obliges scientists to come forward with some other factors called independent variables to reestablish the model as a hypothesis.

The next step is validation. Once the designer uses a set of studies to establish his model, the journalist should check that he has not used those same data as confirmation. The scientific method obliges him to make fresh predictions, leading to new experiments that confirm these predictions. Each new study that agrees with the result provides a measure of confirmation, so long as no other new study provides contradictory results.

"How much confirmation does the process achieve?" one might ask. The study set that formed the basis for the model provides a statistical measure. The scientist can hypothesize that the discrimination according to any subset of the variables was due to chance alone. He can quantify this chance mathematically and give it well-known confidence limits. He can then measure the degree of confidence achieved by later confirming studies.

Note that the complexity of the hypothesis does not enter the calculation of chance in the result. That is, the theory is to no degree strengthened because it applies to very rare circumstances. On the contrary, such a theory receives a subjective discounting for not being robust. It is not very interesting.

Ozone Layer Depletion

How should a journalist handle the current Ozone Layer Depletion problem unfolding in the media? Here is a line of questioning for the reporter from the *Daily Skeptic* to ask the Administrator of the Environmental Protection Agency[20]. This reporter is not a scientist, but qualifies to report scientific issues because he received high school instruction in

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[20]Currently William K. Reilly

the Scientific Method. He qualifies as a responsible journalist for having done his homework before going to the press conference. This reporter deserves a byline.

Precision in the Language.

> Sir, you were reported recently[21] as saying that previous studies showed that the ozone layer had thinned 1% to 3% during the previous 12 years. That article continued, reporting that now you say that the ozone layer has "degraded 4% to 5%" during that time. My first question is on the use of the word *thinned* in one instance and *degraded* in the other. Does this mean that the change is a change in the reported parameter?
>
> According to another report[22], Rich McPeters, who is head of the Ozone Processing Team at NASA, said that the layer decreased 5.5% from 1978 to mid-1990 along 40 degrees north latitude. This is a larger figure, so could you tell us where your data applies? Are you reporting the same time period?

Measurements.

> Do you measure the thickness of the layer in meters? Or does thinning refer to a change in density, or do you, perhaps, measure both a layer thickness and a density? What is the gaseous composition of the ozone layer, and are you reporting the ratio of ozone in a mixed layer? How do you measure ozone layer thinning and the ozone layer hole at the pole?
>
> Since the measurements are made from a satellite or the Space Shuttle, are we to presume that you use remote sensing? Does this mean that you don't actually detect ozone by collecting samples but measure some property of the layer, like its

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[21] Los Angeles Times, April 5, 1991

[22] Orange County Register, April 5, 1991

absorptivity, reflectivity, or transmissivity? Do your measurements presume a location of the layer in altitude, as in six miles above the surface, and does that altitude vary with latitude, longitude, season, or climatic factors? Are your measurements dependent, for example, on the position of the sensing instrument and the location of the layer? If that is true, how do you know that you are measuring ozone? For example, are you actually measuring ultraviolet energy transmitted through or reflected from the layer? Are your measurements affected by the instantaneous UV radiation from the sun at the time of the measurement? Do you simultaneously calibrate against the solar UV emissions?

Do you monitor the intensity of UV radiation at the surface of the earth? Do those measurements correlated with the reported thinning of the ozone layer?

You reported that the previous measurements were in error. Would you please tell us how you discovered the error, how accurate the measurements are now, what assumptions you make in the data analysis, and what limits the accuracy of the measurements?

Media reports now say unequivocally that CFCs cause ozone layer depletion, and this is believed widely enough to have prompted the Montreal protocol[23]. How do your measurements support the theory that CFCs are the cause of the thinning you measured? Does a Cause & Effect relationship come about because you have measurements before and after the advent of CFCs, and that thinning is coincidental with the introduction of CFCs? Do you also simultaneously measure the presence of some agent other than

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[23]The Montreal Protocol restricts the production of CFCs by the year 2000.

chlorine that may take part in the reaction in or near the ozone layer?

Model.

Doctor, how is the ozone in the layer created, and what parameters govern the thickness of the normal ozone layer? Is it caused by the action of UV light on oxygen in the lower atmosphere? If the layer were to thin, admitting more UV to lower altitudes, would the atmospheric system compensate by creating more ozone?

In other words, would you describe for us the stability of the normal ozone layer? What does the model say is the range of ozone layer thickness without the effects of CFCs? Does it exhibit any kind of cyclic behavior? Is it affected by solar activity? Is it affected by the global climate? Does your model for the ozone layer work with a Global Climate Model?

The data you provided suggest a trend in thinning or depletion over a 12 year period. How many data points do you have covering this period? Were they all made with the same sensor and vehicle? How well do the data fit the trend line? What is the variance of the data and how does it affect the variance of the slope?

The famous discovery by Dr. Rowland[24] was a laboratory model. How have you used his results to modify your model for the earth's ozone layer? How are the CFCs released into the atmosphere transported to the ozone layer? How long does the transport take? How long will the CFCs remain there? How fast does the reduction of ozone occur? According to the model, how fast should the layer be thinning? Is that model confirmed by the data? Does the model simultaneously account for the normal

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[24]Of the catalytic action of dissociated CFCs on ozone.

creation and reduction of ozone plus the effects of CFCs? How does your model reflect differences in data between Northern and Southern hemispheres?

How do you model the incidence of UV light arriving at the surface of the earth? Do these measurements fit with your data?

On which of the following, then, does your model for the ozone layer depend: a model for the sun, a model for global climate including models for the oceans and cloud cover, a model for ozone depletion by CFCs, and a model for transport of CFCs into the atmosphere? Do your conclusions follow from models for the epidemiology of skin cancer?

Predictions.

According to the papers, the EPA projected the data over 50 years to estimate the damage to humans. Does this presume a first order model? That is, does your model predict that the trend will continue over that period, or do you have some other model to follow? If it is a continuation of the trend line, how did you estimate the trend line?

Of the other models on which your ozone layer model depends, have predictions been made with all of them?

Sir, according to one of the reports, you predict an excess of 200,000 deaths over the next 50 years. A television report added that you predict an additional 12 million cases of skin cancer. What data do you have showing dose sensitivity of skin cancer to UV exposure? How do you extrapolate the disease case rate to death rate? What parameters and assumptions affect the accuracy of your model? What are the upper and lower limits of sensitivity to dosage? What do you predict the incidence of disease and death to be with a normal ozone layer?

Your reports included a possible increase in cataracts and harm to agriculture. Could you tell us how you modeled and quantified these effects?

Validation.

Have predictions for normal ozone variations without the effects of CFCs been validated? Has any cyclic behavior in ozone been predicted and validated? Have similar predictions with CFCs present been validated?

Of the predictions of other models on which your model depends, have all of them been confirmed?

How has your model for disease and death rates been validated with a normal ozone layer?

Scientists, and both students and teachers of science, should classify the idea that the CFCs are going to destroy the ozone layer, with all the dire consequences attendant to it, as conjecture until these questions and others like them receive satisfactory answers. Scientists will discover the answers to these questions, and the media has a public responsibility to keep the scientists honest and on course. If the media think that the problem is serious enough, then they have a duty to keep the public and public officials informed of scientific progress, not speculation. Responsible citizens can support the international restrictions on CFCs even if it may be an over-reaction in view of the paucity of modeling and data. At the same time as a matter of responsible, ethical science, all those involved should exercise their skepticism. The media should not be a short cut to peer group review.

The odds are that the CFCs are going to turn out to have no measurable effect on the atmosphere! Why? It's not for a lack of trying, or that man wouldn't reek havoc if he had the power to do so. All the fires in all the wars unleashed at once, all the radiation held in all the power plants, all the explosions from all the weapons, all the microwave energy from all the radios, radars, power lines, and ovens, all the energy consumed, and all the waste accumulated are puny along side natural forces. The power that man uses is equal to one twenty four thousandth (1/24,000 or 0.0042%) of the power that the earth intercepts from the sun!

Nothing that man has done so far has had much impact on our conditionally stable[25] planet! These ideas, of course, are heresy! Like some of the reports they challenge, they are mere conjectures. Yet they are based on the Scientific Method and on reasonable extrapolations from data available to the public. The ideas would not find their way into the media because they are discordant with popular beliefs promoted by the media. They are the equivalent of politically incorrect thinking in popular science. To add a touch of cynicism to the skepticism, note that these ideas are also uncommercial.

The U. S. has developed a particular political technique. For a variety of motives, populism and sensationalism exploit low scientific literacy. It is a virus that has spread to the U. S. school systems at all levels, and it continues to infect science education. It is the promotion of beliefs; it is incompatible with science and the Scientific Method; it is unethical. It's time to make these matters part of an ethics curriculum.

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[25]The conjecture is that the earth is conditionally stable in its present state. Too many powerful, natural forces, like volcanic discharges, forest fires, storms, and variations in solar radiation, stress the ecosystems without affecting the long term equilibrium. Scientists and students should examine each model for its stability characteristics.

CHAPTER SEVEN
SCIENCE ISOLATION FROM THE REAL WORLD

To this point, this Strategy for Science Literacy has settled on a concise, testable, teachable definition of Science and the Scientific Method. It has shown that each man is isolated from the Real World by physical distances, by the limitations of his senses, and by the incredibly brief time of his existence. Science satisfies man's needs for something better, tying together evidence into models of the Real World with ever greater accuracy and utility. The next question, then, is does Science ever contain perfection in any of its models? Can Science converge on truth? Is any model ever certain?

UNCERTAINTY

Uncertainty lies at the core of scientific philosophy. This has been true from the beginning of the art, dating to Descartes, Newton, and Galileo. Uncertainty, like guilt, is a basic irritant in man's soul. It is the other side of the coin of predictability, and more because it involves all measurements. Where are we? What is out there? Are we being Guided? And most important, where are we going? Science, like religion and other philosophies, attempts to answer these questions. One difference is that a philosopher argues for or against certitude, and what is or isn't knowable. Science accepts the inevitability of uncertainty while straining against its limits. Science fights uncertainty in both knowing and forecasting, grinding away at the frontiers of both. The irritant of uncertainty seeds the pearls of scientific predictions and technology.

What does certainty mean? Safe in one's knowledge, to be sure, but also the ability to predict.

Need for Predictions

Man may share his aversion to uncertainty with the animals. Events reinforce this conjecture daily. What is curiosity but an inquiry into uncertainty? What are the biological clocks but conditioning to a pattern in the noise? Domestic dogs and cats want to know what is going to happen. A dog will race to the back door when his master picks up his car keys from anywhere in the house. From there, he is content to watch the daily departure.

A cat named Cogburn is the rooster of his household. He will lie by his masters' bed until dawn. (They don't allow him on the bed when anyone is in it.). If his masters don't get up, he will stand by the bed. He taps one master then the other on the arm or face until someone gets up. Once one is up, he's satisfied — about half the time being content to curl up on the floor and go back to sleep. Cogburn needs the ability to predict the events in his days. Pets need to predict what is going to happen in their environment, whether they understand it or not.

Parents of handicapped children learn how dependent children can be on certainty and the pattern of routine. This is a well-known phenomenon to therapists and parents of more severely handicapped children. A simple break in routine, like setting the table with spoons and forks interchanged can precipitate an emotional outburst and breakdown. These unfortunate children desperately need certainty in the most routine parts of their difficult lives.

Need for Explanations

An argument with some subjective satisfaction is that the objective of science is to explain. But when is a phenomenon explained? If the criterion is satisfaction or consistency, then a subjective test has been applied. This is a foul. Tweet! Out of bounds! Fifteen yard penalty! A scientific criterion must be objective.

Perfect Organisms. Biology (C90) asks, "Does Evolution Fashion Perfect Organisms?" It answers, "In a word — no." The reasons it gives are

(1) evolution builds on imperfections of the past & doesn't start from scratch,

(2) Adaptations are compromises,

(3) Not all evolution is adaptive, "Chance probably affects the genetic makeup of populations to a greater extent than was once believed." And,

(4) Natural selection works on what is available, not creating custom genes.

There is a much better reason. It is simpler, and it transcends these four reasons. The question is beyond science! Science can't even answer the question of whether or not a variation is an improvement. Science is not competent to know whether or not a change is better let alone if an organism is perfect!

Hypothesize that the opposite is true. What kind of experiment might a biologist conduct, and what would he measure to validate it? If a variation survives in greater numbers, is that superior? Suppose, for example, that a new variation drives the previous into extinction, and then fails to survive a minor environmental change that the first had always survived? For example, a long period of abundant water might allow the atrophy of the ability of a variety to survive drought. The question of superiority is subjective until someone supplies a measurable. Science doesn't have the ability to do that. Science has no way to supply the criteria of goodness.

NATURE'S LAWS

Philosophers argue whether or not there are laws in nature, what they consist of, and whether or not they are universal. Scientists instead examine the facts for some order. This order, called patterns, consists of structure in the measurements. Scientists look for patterns imbedded in the fog of uncertainty, called noise or randomness, attached to the measurements. Patterns imply repetition, usually in time or space. Patterns are the stuff of laws. The Laws of Conservation are patterns, often expressed as symmetries.

No one can be sure, but suppose nature has a process that is truly random. Maybe an example is evolution as the Strategy models it. That is, life is opportunistically changing, probing the environment for a niche for a new form. For the sake of argument, suppose those random mutations are indeterminable. Doesn't this mean that the model can never predict? That the theory can never be validated, and is doomed to being a hypothesis forever? Perhaps .... .

Perhaps in the beginning a Devil created the environment and God responded with DNA! The universe is expanding from a fantastic fire ball, and Man is hanging ten on the shock wave of an incredible explosion!

SCIENCE IS SHARING

Individually, each person is stuck with his senses and his brain. There's not a lot any of us can do to improve them when they are operating normally. Our observations are always a small part of the Real World, limited in about every conceivable dimension. We receive brief projections of the Real World onto our narrowband, small dynamic range of senses and sensors. These are the clues that allow our models to represent only a portion of the Real World. Einstein taught,

> Physical concepts are free creations of the human mind, and are not, however it may seem, uniquely determined by the external world.

This was quoted in Chapter 4 as it applied to the individual mind, and it applies as well to the collective knowledge of any field of Science. Perception is a subjective process, shaped by experience and mood, and highly unreliable. A goal of science is to escape the subjective, replacing observations with measurements, and extending the domain of measurements beyond what is observable to the senses.

Fortunately, people can use their brains to link with other brains, expanding their perception, increasing both its accuracy and its utility. As much as all the individual cells of a brain are more powerful when they work as a whole, the collection of our brains is more powerful than any individual brain. In a manner of speaking, man can make an array of his brains.

Our brains are especially geared to work in conjunction with one another! We inherited the capacity for language. We either inherited logic with language or we invented it. And we have invented mathematics. These things allow us to communicate unambiguously, or, as engineers say, coherently. If our brains, like antenna elements, are going to work together in synchronism and efficiently, our first order of business must include precision in the use of language.

Science cannot deny that people might reinforce subjective notions by sharing knowledge in concert. A community may substantially agree on what is art or beauty, on the value of faith, or on the manifestations of a supernatural force. Science proves or disproves nothing in the Real World. Science cannot even say that it has properly accounted for a phenomena. Science does say that if certain conditions happen in the Real World, then a certain thing will be observable. These are its predictions, and the value of Science rests on them.

LOGIC AND MATHEMATICS FROM LANGUAGE

With minor variations, this popular example from the last chapter has many aliases:

THE BOXED SENTENCE IS FALSE.

This is Catch 22, Russell's Paradox, the Liar's Paradox, the Barber Paradox: "An exclusive barber shaves everyone in town who doesn't shave himself. Does the barber shave himself?"

This problem relates to the Law of the Excluded Middle. This law is variously a law, a theorem or a postulate, depending upon how the logician formulates his version of the symbolic logic. When it is a theorem, it is proved using the method called Proof by Contradiction. In this case, the assignment of logical values in the truth table implies the result. This is the entertaining theme of self-referencing in the Pulitzer prize winning work by Hofstadter (1989).

Bertrand Russell called the problem statement *impredicable*; meaning that the predicate was not well-formed. Russell then created his elaborate theory of types in logic to handle the problem. A school of mathematical philosophy set about to develop a mathematics absent the Law of the Excluded Middle, putting all of mathematics at risk some said. Another school attempted to derive all theorems by construction, avoiding existence theorems which prove that something must exist but produce no specimens.

The mathematician Kurt Gödel earned his place in history tackling this problem. He turned the mathematical world on its ear in the early 30's with a pair of theorems. It has yet to recover. According to Kline (1980), it marked the loss of certainty in mathematics. In one sense, Gödel had proved that the Law of the Excluded Middle doesn't hold! This is much more than a simple discrepancy in logic or mathematics, for it strikes at the heart of language itself. If logic is hard-wired into our brains and if it includes the Law of the Excluded Middle, Gödel proved our brains defective.

Mathematicians had been seeking proof that any system of mathematics was consistent and complete. Of course, they define these terms precisely, as the Strategy demands of all science: to wit,

> Consistent means that no formula and its negation would both be provable in the system; and

> Complete means that every proper statement in the system or its negation is provable.

With this as background, here is a table of possible classifications of a system, S. Heuristically, P could stand for any proposition, and S for Science.

	For every statement P in S		S	
State	P	~P	CONSISTENT	COMPLETE
1	PROVABLE	PROVABLE	NO	YES
2	PROVABLE	NOT PROVABLE	YES	YES
3	NOT PROVABLE	PROVABLE	YES	YES
4	NOT PROVABLE	NOT PROVABLE	YES	NO

PROPERTIES OF LOGICAL SYSTEM
Table 7-1

Now by the Law of the Excluded middle, a statement, here labeled P, must be either true or false while its negation, ~P, has the opposite assignment. Provable means that the statement proves true by following a prescribed set of logical operations.

Kurt Gödel first showed the existence of a clever statement with two properties. First, his statement is true but unprovable in symbolic logic, and its negation is unprovable if the system is consistent. The statement is analogous to the Liars Paradox. Suppose the sentence P says,

"The sentence P is not provable[1]."

Note that this sentence is self-referencing! Now the statement P must be true, for if P is false then it is simultaneously provable and false. This is not permitted by the meaning of provability and the Law of the Excluded Middle. So Gödel used the classical paradox to construct a sentence which is true but not provable. Moreover, since it is true, its negation is false and cannot be provable by the same argument. The logic system is incomplete if the Law of the Excluded Middle holds[2].

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[1]Provable means provably true, of course.

[2]To the Strategy, another alternative is apparent. Perhaps a consistent system should not allow self-referencing!

Next Gödel constructed a clever proof using P to show that the statement,

"The system S is consistent"

is unprovable in a formal logic system. If this, too, sounds like self-referencing, it should! It was an inquiry into self-referencing at the outset, and it had to have self-referenced formulas or methods in its proof. Gödel showed that a formal system, including logic and arithmetic, could not be both consistent and complete and that it could not be proved consistent. One would have to leave such judgments to a higher authority, called *metamathematics*.

These formal reasonings are the background for the serious conjecture advanced in Chapter 3 that a human brain will never be able to understand itself completely. The idea does not derive from the complexity of the Gödel problem statement, but from its consequence. Apparently, the individual brain cannot be consistent and complete if it is logical.

This puts one in mind of the on-going attempts to establish contact with other civilizations in other galaxies. Scientists are sending the digits of Π by radio, hoping that some future, distant civilization at least as advanced as ours will receive it, decode it, and send a message back for our descendants. Sort of an intergalactic sharing!

Some have said that man invented mathematics. What happens to our signal if perchance we invented Π? Suppose some intelligent civilization also discovered plane geometry, but discovered that the diameter of a circle is in a fixed ratio to the circumference, not the reverse. That is, they discovered $1/\Pi$, calling it Π'! Suppose they started transmitting those digits to us:

$$\Pi' = 1/\Pi = 0.31830988618379 \ldots$$

Or what if that society had never invented the decimal system, using instead continued fraction expansions! Maybe their compressed string of continued fraction coefficients have been coming since before Marconi! If digits from one of these sequences arrived here deeply buried in intergaláctic noise, we just might not recognize it at all!

The workings of nature are highly complex and non-linear. Man's models of nature always inherit a residue of the limitations of resolution, accuracy, and scope in time and space that reside in his measurements. His models are further constrained by man's ability to calculate. Scientists begin with zeroth order approximations. They add dimensions, meaning degrees of freedom, to the model as they find patterns in the residual error between model and facts. The process continues and the models become more and more complex, quickly and easily departing from the linear world.

MENTAL CONSTRAINTS OF SCIENCE TRAINING

Teaching Science as the shallow fun and entertainment of Gee Whiz experiments is a mistake. Science is not hikes in the mountains, playing with chimpanzees, random experiments with colorful chemicals, nor games on computers. Science is a disciplined way of understanding the world that provides a much more enduring intellectual satisfaction. The rewards are proportional to the effort right from the beginning of studies. Science is as deep as any knowledge, but it is not free form. One might argue that these intellectual rewards are more satisfying than any of those in entertainment. Science should be enjoyable, but as mind expanding knowledge, and not showmanship catering to the spirit of hedonism in the American drug culture, the me-generation, and the latest delusions of empty self-esteem known as the "Feel Good Movement".

The objective nature of scientific thought is a mental discipline. It is a restriction of mental freedom, and each student needs preparation for this potential problem. He needs discipline to reject the ambiguities in subjective experiences expressed with words, images, and ideas. Science training teaches the student to think in this disciplined way. It enables people to share experiences in a constructive way.

Properly forewarned, the student will learn not to be mechanical as a consequence of his scientific training. He will learn to channel his mental creativity in new directions, not to dampen it. He will leave a trail of new objective creations. He will always be free to challenge and hone the old definitions, but he can not willy-nilly ignore them. There is a lot for him to learn by challenging the old — like an archeologist sieving an ancient dump.

The well-trained student will learn to enjoy both his right-brain and left-brain experiences, and to understand the differences. He will learn to make the two halves work together to the enjoyment and exploitation of the creative challenge in science. He will find beauty in science — from patterns, to the intricacies of an organism; in symmetry, in a mathematical theorem or proof. He will find satisfaction in discovery and in the adventure. While he might also find much that is ugly or smelly or yuckie, these are quickly forgotten for the subjective but rewarding aspects of the objective whole of science. Beyond the satisfaction of acquiring knowledge, the trainee will also be developing skills to be a productive member of a technological community, reaping objective rewards as well as the subjective satisfactions.

WHAT SCIENCE EXPLAINS

Will Science training explain the Real World to the student? Will he find things proved? Just what is the power in scientific models to explain?

Problems with looking to science to explain, first broached in Chapter 4, are semantic. As discussed previously, the narrow definition of the verb *to explain* is *to account for*. This is consistent with our definition of Science and the process of *accounting for* occurs in the best of science. In this narrow sense, explanation is a weak, albeit essential, process of simplification. In this sense, explanation lies entirely within the purview of Science.

There is also a set of broad definitions, where *to explain* means *to make comprehensible*. This is the strong sense that brings in the subjective element of satisfaction. Does this scientific model or that explain a phenomenon to the listener? Science doesn't know and can't say. Now it might happen some model does explain in the strong sense, but whether or not it does is reserved to the recipient of the message. A sufficiently obscure explanation is useless. This is analogous to the old riddle of the tree falling in the forest, and whether or not there is sound absent a creature to hear it. It depends upon the meaning of sound. Objectively, dictionaries will define sound as a vibration in a medium; subjectively, the definition is the perception in the brain of such a vibration.

To Prove

Exactly the same problem holds with definitions of *to prove* or of *proofs*. Two noted authorities on symbolic logic, Kalish & Montague (1964), provide a narrow definition,

> A *proof* is a derivation from an empty class of formulas [which results in a theorem].

A proof in this sense is the extension of axioms through permitted, rule-based steps. This bounds a proof within the realm of the formal system of logic; this kind of proof is a scientific process. This kind of proof can make no test of any logical sentences or of the axioms of logic themselves as to their appropriateness as models of the Real World.

Hofstadter (1989) begins to bracket the broad definition, saying first,

> A *proof* is something informal, or in other words a product of normal thought, written in a human language, for human consumption.

Then he adds,

> A *derivation* is an artificial counterpart of a proof ...

seeming to address and even to denigrate the formalism of Kalish & Montague. Hofstadter gives his readers some attributes of a subjective proof, but quits well short of a complete definition. Science can help a little with the definition, but in the end science has considerable power to persuade and little to prove.

Cause & Effect (C&E)

One can engage a philosophical question of whether Science can ever show a causal relationship. A scientist might convince himself to a moral certainty, but how does he prove Cause & Effect? He can only measure and correlate. Scientific models invoke the Principle of Cause & Effect, but causation is a subjective interpretation of the models as they relate to the facts. The most successful model, a Law, may be overturned. It may one day receive an entirely new interpretation. The hypothesis part of the model which embodies the causative agents, may be split in two. Science does not have the power to prove Cause & Effect.

Mathematics imposes Cause & Effect by designation of independent and dependent variables. The independent variables are the causes, and the others the effects. The implications are strictly formal, often designated by the way the mathematician chooses to group variables on each side of the equal sign.

A scientist might correlate the pieces in a scientific puzzle mathematically. This is a technical measure of simultaneity, which is the occurrence at the same place in time-space coordinates. In mathematics, time and space have no special distinction, for each is simply a coordinate or dimension.

The general application of the C&E Principle is not a denial of randomness in nature. Rather, it is the discovery of a pattern within the background of noise that the scientist tentatively incorporates into a model. He tests to see if that pattern will occur again in sufficiently similar circumstances. The mission of the scientist is to establish those circumstances, for often the pattern is fleeting or relates to yet unidentified causes. Not only does Science say that randomness exists, but that it is inevitable in everything. This is not a denial of C&E. Randomness appears in all measurements where it flows into all models. At the margins, Science cannot differentiate between randomness in nature and randomness due to limitations in knowledge or facts. Science is on a perpetual quest to reduce randomness. Science is never content to declare that here is an Effect absent a Cause. Science is perpetually seeking the pattern in the residual noise, applying the Principle of C&E.

C&E is especially tenuous when dealing with statistical correlation. Statistics are measurements, and mathematical correlations point to possible C&E. The correlation is strongest when a process consumes energy and the measurements include the source of that energy. If that source is unique and contributes the proper amounts to the reaction, then it is with some confidence the cause. Experiments may seek to block this flow of energy suggested in the model. If successful, the C&E relationship is greatly enhanced. Nonetheless, after all this effort, it retains some subjectivity.

Cause & Effect in Biology. Cause & Effect is key to science, to its explanatory powers. Nowhere is that more important than in biology. A student might infer from words like "evolutionary pressures" found in biology references that evolution is the cause and genetic change is the response. What kind of evolution does the adjective evolutionary refer? Part of the problem is Cause & Effect, and part is semantic.

Consider the following from the Encyclopedia Britannica:

> Since there is evolutionary pressure to reduce the length of time between generations, ... EB86, Vol. 20, p. 425

Does evolutionary pressure mean an impetus to change caused specifically by changes in the environment?

> There will always be some natural selective pressure for the shortening of the generation interval, simply out of a natural economy, and for an increase of the number of offspring produced by any reproducing individual. EB86, Vol. 20, p. 424-5

This passage poses two big Scientific problems. First, it presumes that a greater reproduction rate, here in the form of a shortened cycle and more offspring, produces a more economical variety. This is neither a law nor a principle in Science. It is a phantom model, unwritten and unvalidated.

Secondly with regard to Cause and Effect, the passage suggests the presence of an external force able to cause a species to create a variant with greater reproductive capacity. Neither evolution nor economy can be such a force. This is too close to the hypothesis of inheritance of acquired characteristics, a discredited biology model that resisted all attempts at validation. Instead the Strategy will show in Chapter 10 that diversity or variability built-in to the life forms is a sufficient assumption.

Power of Science

Does Science represent the Real World? Is Science accurate? Does Science find Cause & Effect in natural processes?

All fields of science make assumptions or adopt axioms that give man subjective confidence that his models represent the Real World. Elementary physics experiments require assumptions about idealized solid shapes with uniform density. Advanced physics entails models of particles that are vanishingly small. Familiar examples from mathematics and logic include concepts like the several axioms of geometry, the axioms of integers and real numbers, and the axioms of the processes of inference and truth assignment.

Since every measurement has an error, experiments always differ from the prediction of models. This is true even when a scientist counts objects or events. He can generate miscounts, or make errors of judgment as to what constitutes a proper object or a proper event. Every attempt he makes to place a discrete occurrence in time or space faces an ultimate accuracy in those coordinates. He attempts to reconcile the differences by analysis of the errors, taking more data, refining the experiment or the model to obtain better closure. In the end, though, he still has a residual error. That residual error is an indelible part of the model.

The power of science is its ability to predict. Man inherits his need to know even the simple future, and science is the only field with measurable success in that endeavor. The study of science is unique in personal satisfaction gained from predictions of the natural world. The curriculum should impress upon students the power of science to predict, a power that points to discovery and invention. Students will come to appreciate the beauty in the proof of a theorem and the elegance in scientific expositions. Their studies will prepare them for the technology that expands their senses, extends their reach, and empowers them as citizens.

PRACTICAL SCIENCE

The loss of certainty in modern science bothers the practicing scientist little. He views entertaining epistemological discussions as academic and highly theoretical diversions. Perhaps the practical scientist becomes too inured by the hard knocks of making physical models work according to theory, and then applying them. The industrial scientist does not depend on certainty in his science. He never expected it, and its absence can't disappoint him.

The issue here may be trust in a classical false hope of theoretical science. That is the existence of an à priori knowledge of the Real World. The practical scientist must fit his theory to the Real World through his underlying assumptions or axioms. This is a pragmatic psychological anchor that to some extent is denied the theorist.

Mach challenged the existence of the atom, preferring to think of matter as continuously divisible. His contemporaries had in mind fundamental particles configured in submicroscopic planetary systems. Now each subatomic particle may be infinitely divisible into something else! Neither Mach nor his contemporaries was quite right. Everyone can be confident, though, that all parties were intelligent individuals. Each would revise his thinking if they were resurrected for an up-date course on the progress of physics. A person is wrong in his speculations only when he ignores the data.

Mach may have been close to the target when he speculated that matter is forever divisible. However, when matter is subdivided far enough, its state and its macroscopic attributes change. This is an extension of man's experience with the Real World at every scale. Non-linear effects are everywhere. Parameters appropriate to objects and processes in the Real World are scale dependent.

One of the earliest breaks with certainty was the famous Heisenberg Uncertainty Principle of quantum mechanics. Philosophers have made much hay out of this profound straw. The Principle says that the precise location and momentum of a particle cannot be determined simultaneously. It also says that the energy and the time of observation cannot be simultaneously determined beyond a limit. More precisely, it says that the product of the uncertainty of certain related pairs of parameters[3] must be greater than Planck's constant. Physicists use this to say that we can determine the precise position of an electron in its orbit, but not its momentum, or the reverse. This places the Uncertainty Principle as some natural epistemological barrier, one with almost supernatural powers.

Could the Uncertainty Principle be not about what man can know or measure, but a statement about the nature of matter itself? That is, could it be that the Heisenberg Uncertainty Principle is saying that the electron doesn't exist in its orbit as a discrete particle, one with a location and a momentum? Perhaps instead, the electron exists physically distributed, like a gas of pure energy. In this model, it would exist as a particle when stripped from the influence of the nucleus.

On the other hand, perhaps the Heisenberg Uncertainty Principal is an à priori consequence of man's choice of manufactured parameters to describe small things. Perhaps it is a mathematical tautology, wired into the model. The Uncertainty Principle is not a Law because of its origins. It is

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[3]Called conjugate variables.

derivable from man-made definitions of parameters, especially frequency and time. It is not quite à priori knowledge because it deals with man's model of a parameter called frequency.

The Uncertainty Principle has a parallel in logic. Each deals with the definitions man assigns to words, the modeling of the meaning of words. In one canonical form of logic, we have AND, OR, IF ... THEN, NOT, and methods of proof. In physics, we have frequency and time.

This discussion is neither an argument against the existence of the Real World, nor that Science is somehow weak in its representation of that World. Instead there is a demarcation between Science and the Real World that Science can never exactly and certainly cross. The goodness of fit of scientific models to the Real World resides finally in their predictive value. Science deals with projections of the Real World in manmade models. Those models over the years get better and better at predicting what is going on "out there", but "out there" they must remain.

ON THE MEANING OF RANDOM

Random describes a state of knowledge or purpose. It is the seeming absence of a plan or purpose. It is the uncharted area of our knowledge. In this sense, is all philosophy about random things? Does randomness exist in the Real World? Science searches for patterns among random events. Einstein may have been winking at us when he said, "I shall never believe that God plays dice with the world." Random contrasts with determinism in science as the apparent absence of cause.

Determinism (Lat. *de + terminus*, end) is

> The doctrine that every fact in the universe is guided entirely by law. Contained as a theory in the atomism of Democritus of Abdera (q.v.), who reflected upon the impenetrability, translation and impact of matter, and thus allowed only for mechanical causation. The term was applied by Sir William Hamilton (1788-1856) to the

> doctrine of Hobbes, to distinguish it from an older doctrine of fatalism. The doctrine holds that all the facts in the physical universe, and hence also in human history, are absolutely dependent upon and conditioned by their causes. (R84)

Papoulis writes on "Determinism versus probability",

> As we have already pointed out, many students are skeptical about the physical validity of a probabilistic law. They are used to the idea that a physical law describes the deterministic evolution of nature and a probabilistic interpretation is necessary only because of our ignorance. The controversy of determinism and causality versus randomness and probability has been the topic of extensive discussions. In our opinion, the difference lies not in the nature of this or that phenomenon, but in the quantities in which the observer is interested. If he is interested in the outcome of one experiment, then his statement is deterministic; if he is interested in certain averages of a large number *n* of experiments, then his statement is probabilistic. In either case no categorical assertion is possible. In the first case, the uncertainty of his conclusions takes the form *within certain errors and in certain ranges of the relevant parameters*; in the second case, *with a high degree of certainty if n is large enough*.
>
> ... One sometimes associates probabilistic phenomena with discontinuities between cause and effect. A slight variation in the angle of [coin] tossing might change the outcome from heads to tails. This is, perhaps, best demonstrated by the familiar experiment of a ball falling through a pinboard. However, such discontinuities depend again on what we consider as effect in a given experiment. Suppose, for example, that a computer converts an analog input to a digital output and it records this output up to the tenth decimal place. If we can measure the input only with a 10^{-5} accuracy and we consider as effect the last decimal of the output, we shall observe a discontinuity between cause and effect. In fact, so far as we can tell, identical inputs

(causes) will result in distinctly different outputs. (P65-pp. 15-6)

Probabilistic models trouble not just Papoulis' college students, but most adults. Business forecasting, for example, is a deterministic process today. Future programs are assumed to be either winners or losers for planning the future activity of a Profit and Loss center. The result is often measurable misplanning — wrong staffing, wrong capitalization, wrong investments, and misdirection as to which new projects management wishes to pursue. Executives make commitments and direct new business pursuits on the basis of subjective guesses as to discrete wins, often using political criteria[4]. The scientific alternative is in include all prospective new products in the plan, but with each weighted by its respective probability of surviving to each stage. Even though the probability estimates are subjective, the result is a statistical future business profile which is relatively insensitive to the assumptions. This is a powerful, non-deterministic technique for business strategic planning. It yields the best possible planning and scheduling of investment, including manpower, material, and plant resources. Unfortunately, much less than 10% of technical managers understand such techniques; and fewer financial executives can cope with the method. Certainly, many more understand it than employ it!

By no means are the shortcomings in non-deterministic thinking in industry limited to executives doing business planning. Many professionals with advanced technical degrees are beyond learning and applying non-deterministic methods in their work. This is the conclusion of trainers assigned to train industrial leaders, engineers, and scientists

[4]E.g., which new products have the requisite career potential, which can be made to appear most reasonable for investment, and which is about the right size for the portfolio of a growing, robust business center.

in stochastic modeling[5]. The difficulty has the appearance of a capability of the human mind that atrophies when not developed in time. Exposure to dealing with uncertainty should begin at the earliest opportunity and remain indefinitely in the curriculum. It is painless and fun. Early training prepares the mind and keeps it open for future theory, and for life itself.

The difference between Cause & Effect and randomness is not so much a matter of the nature of the processes in question. Science has many unsettled questions about whether or not nature executes a process randomly. Are there random walks in nature, or is the randomness man's limited ability to know and measure? If it isn't measurable, scientists can't model it. Nonetheless, measuring does not assure that the derived model will capture any Cause & Effect relationships. For example, the presence of a protein during a biological process might be a coincidence, or itself a parallel consequence of a different, unsuspected causative agent.

The deeper philosophical question is whether or not there exist true random processes in nature, phenomena for which there are no causes. A true random process is one which is random quite independent of man's models, some call it *ultimate randomness*. This is a much different question than whether or not Science can obtain complete knowledge economically.

At the next level, there is a question of whether or not ultimate cause is knowable to man through Science. Natural laws may block Science in one of two ways. First, the absence of a cause may be unprovable. Second, an ultimate cause might not be measurable because of some principle like Heisenberg's. Physics at the quantum mechanical level is at that state today. The answer to both speculations appears to be affirmative. This is the threshold of knowledge in physics,

[5]Modeling with statistics or statistical information.

laced with dilemmas and amply targeted with research and speculation.

Perhaps the division of chromosomes at meiosis contains ultimate randomness. Mendelian theory reduced random phenomena to laws. Suppose biologists find a protein that causes specific cross-over patterns during meiosis, or another that causes Alzheimer's. This is great science, and may lead to control of genetics or a terrible disease. Now, the questions just shifts to what caused the protein? It cannot end.

Science observes and measures. Scientists seek patterns in the measurements, and model them in anticipation of a repetition of the pattern. This modeling process implicitly includes Cause & Effect — a principle of Science. Science cannot know that an effect is causeless, only that it hasn't found a pattern and hasn't hypothesized a Cause & Effect relationship.

Every measurement has an accuracy, which is a positive way of saying that every measurement contains an error. Every description of a relationship is subject to reexamination and question. As a result, even if the underlying process has a cause, even if a model is a deterministic expression, it must have a non-deterministic quality. Science continuously works to push back that threshold of knowledge. Science strives to move into non-deterministic territory, to improve the accuracy and resolution of measurements and to provide more accurate controlling parameters in models. Where Science is unable to provide a deterministic model, it produces a stochastic model. In fact, a mature science will always have both. As a consequence, much of man's ignorance lies in probabilistic expressions.

Still our mathematical models extend beyond the Real World to infinity. Science leaps the Real World, extrapolating from a small space to an impossibly large or small space. All observations require finite energy to trigger thresholds. This is the low end of dynamic range called *sensitivity*. Our physics stops temporarily at some particle or energy bundle size. Then the next wave seeks to subdivide it further, looking for the unattainable infinitesimal. Mathematics, though, needs no particle accelerator, and happily lets $\Delta x \to 0$ with a Number 2 pencil.

Scientists invariably observe that no matter how well they measure, there remains a fine structure below or beyond their measurements. This presents itself as noise. So they refine their measurements on the micro or macro scale, trying to find a more precise or a more general description of the pattern. They study the noise looking for additional patterns. From a modeling standpoint, this is the fine structure, also known as higher order effects.

BIBLIOGRAPHY

For an enjoyable excursion down the road of self-referencing systems, read the Pulitzer prize winning *Gödel, Escher, Bach* by Douglas R. Hofstadter (H89). This is a delightful, insightful, rich, deep, self-referencing excursion into computer science, number theory, logic, music, art, and self-referencing. It's not for the faint-hearted, though. There are some difficult, sophisticated chapters, perhaps some simple concepts disguised through complexity, and complex issues weakened through over-simplification. Nonetheless, Hofstadter brings the philosophy of science, art, music, and science (logic, language, math) down a level for human consumption. In so doing, he had to sacrifice much rigor, and he often strains his models. Still it's brilliant, especially in the philosophy. He has an introduction into Zen, but his explanation of the record player is a bit too obscure.

For an interest trip into the uncertainty of modern physics, read *Dancing Wu Li Masters: An Overview of the New Physics* by Gary Zukav (Z80). Quantum physics contains concepts that challenge validity of the comfortable rules of logic. Toward the end of the book, Zukav's path toward Zen reveals itself; this is a good place to quit.

For a moving and entertaining treatment of knowledge from the viewpoint of the field of Artificial Intelligence, try *Computer Power and Human Reason: From Judgment to*

Calculation by Joseph Weizenbaum (W76). Keeping up with this distinguished author wasn't too difficult until he dropped the last shoe: he claims that the pursuit of artificial intelligence, whether that pursuit is meaningful or not, is unethical!

For a thoroughly scholarly and digestible treatment on the frontiers of knowledge, read *Mathematics: The Loss of Certainty* by Morris Kline (K80). This sticks to the business of science from cover to cover. Then, if this doesn't quench the appetite, read the sequel: *Mathematics and the Search for Knowledge* (K85).

CHAPTER EIGHT
TECHNOLOGY

INTRODUCTION

Prediction, not the elusive Explanation or Description, is the fruit of basic science. Prediction's big sister is Technology, the fruit of applied science. In one sense, *technology* means a branch of science and in another usage, *technology* refers to the products of that knowledge. *Technology* as knowledge concerns the manmade world of objects, processes, and information. In this latter sense, *Technology* is the inevitable and unavoidable standard for material wealth of a society. For example, direct correlations exist between societies' standards of living, energy use, and states of technology advancement.

Technology serves man by transporting or transforming material, energy, or information. It includes

agriculture & food stuffs,
appliances — dishwashers, robots, & spacecraft
chemicals & drugs — biotechnology, manmade
    lifeforms
communication,
computers,
containers & packaging,
energy,
entertainment,
fibers & textiles — clothing, paper
information — system science, software
life support — air conditioning, lighting,
medicine,
protection — police & fire,
sanitation — waste management
structures — bridges, buildings, materials
tools & instruments,
transportation — vehicles, terminals, highways,
    ships
water,
weapons.

Technology surrounds man in mundane things like safety pins, video tapes, dripless spouts, and rat traps. As the list above should suggest, the huge majority of students who will use their science training professionally will do so in technology, not basic science.

Technical literature will use the word *technology* in reference to equipment, meaning hardware and perhaps software. For example, an engineer will say, "We made this computer in 0.2 micron Gallium Arsenide *technology*." Or, "What *technology* did you use?" The meaning will be clear from the context.

Cold Fusion

Cold Fusion, a conjectural example of a technology, would transform energy. It would convert energy from a form of nuclear potential energy by the fusing hydrogen nuclei into helium nuclei, creating heat. Later man could use this heat to drive turbines in many applications, doing work directly, like turning a propeller to drive a ship or an aircraft, or indirectly as turning the shaft of a generator to produce electricity. It promises cheap energy for the entire world.

Remote Sensing

Technology includes the application of science to basic science, a process that opens the windows of science. Remote sensing is an example with breadth and pedagogical value. What science knew of the solar system before remote sensing is minuscule by comparison with what is known today. Remote sensing is the prelude to manned travel in space, and is one of the natural attractants for the young mind.

A spacecraft transports equipment, transforms energy, and processes and communicates information. Like the earth from which it was born, it takes energy from the sun for primary instrument power. This power drives electronics that sense, that convert energy collected by the sensors into signals, that broadcast those signals home to earth, and that receive directions from earth.

For the spacecraft, the most common form of sensed energy is photons emitted or reflected from objects in space and gathered by passive sensors. Other sensed energy includes magnetic fields and energetic particles that cause reactions in the on-board electronics. These electronics analyze the energy, measuring its parameters, such as its color and intensity along with its time of arrival, modulation, and spatial direction. The electronics store the measurements, and later code them as electrical modulation on carrier signals for transmission at best efficiency to earth at convenient times and places. Once received, electronics on earth collect the signals, remove the information, store it, and convert it for human perception.

Radar is a principal form of remote sensing. Radar is normally active, meaning that the sensor itself supplies the energy that it later detects and analyzes. Radars today produce high resolution, three dimensional maps of earth as well as planets and their satellites. While the maps of radars cannot be as fine as optical images, radar can penetrate darkness, haze, and clouds. This technology also provides direct measurement of distances and rates, allowing engineers to create three dimensional models of sensed objects. Today, laser radars perform similar functions in the light domain.

Remote sensing by spacecraft is an obvious example of extending the human senses in the spatial direction. Not only can man get much closer to objects like planets and asteroids, but he can reach outside the distortions and filtering of his own atmosphere. In another sense, man can gain perspectives not possible from earth, as looking at the far side of the moon, or looking back at his own planet.

Remote sensing extends man's senses in another way, in the spectral domain. Engineers extend our senses into the infrared and ultraviolet regions of the optical spectral domain. They reach deep into the electromagnetic spectrum as when they build instruments to detect, measure, and analyze radio frequency emissions, Gamma rays and X-rays.

The concept of remote sensing extends naturally into the microscopic and into inaccessible areas. Optical microscopes still provide wondrous spectacles for the student. In the laboratory, the electron microscope and X-ray diffraction continue to open new worlds of discovery.

Fiber optics and X-rays connect medical technicians to the interior of the human body. The familiar images now created of the inside of the body through advanced signal processing techniques never cease to amaze. The technology today not only performs imaging miracles, but reduces the risk to patients by using much lower power X-rays. The most exotic technology in regular use today uses magnetic resonance to produce high quality images of a different type with energy that has no known side effects.

In yet another direction, robots take sensors into hostile environments, from Mars to nuclear reactors and crack houses. Robotics is an industry still in its infancy. It holds many problems in artificial intelligence, involving the integration of signals from multiple sensors, perception, and decision making.

ENGINEERING PRACTICES

Technology applies the Scientific Method in the discipline known as engineering. In the practice of engineering, science and technology blur. The differences become subtle and semantic. When engineers create new products, they pursue a process called *development* that transforms basic science into technology. The line of demarcation is hard to recognize, even though the distinction is crucial to corporate profits.

A popular stereotype, especially by manufacturing managers who are competing for the corporate purse, is that engineers perpetually try to perfect a product. This is earned where engineering managers miss the boundary when basic science should have turned into technology. It happens through a failure to set practical objectives that efficiently bridge from one stage of development to the other. Without this kind of structure, engineers have the dilemma of not knowing when any job is done! This is a disease pandemic in American industry and government.

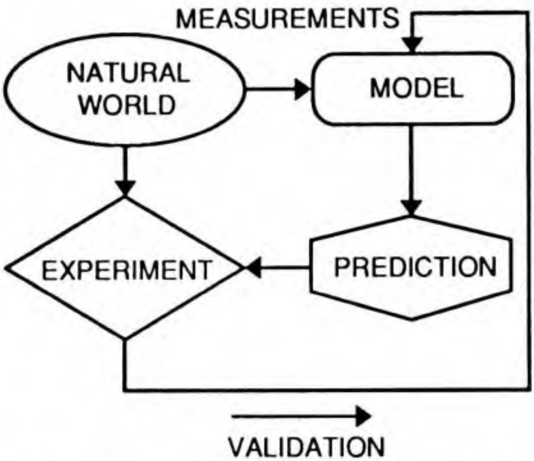
Technology differs from basic science in a simple way. The two arts are parallel, except that the domain of technology consists of physical models in place of naturally occurring objects and processes. Therefore, technology at each juncture works with a pair of models, a physical model and typically a theoretical model representing the physical model. This is the essence of the distinction between basic science and technology. It is shown schematically in the two figures at the top of the next two pages.

In the general form, the physical model, called a *prototype* in the righthand figure, satisfies the novice's sense of the word *model*. The performance model is an abstract or analytical representation of the prototype based on natural laws. As required in the definition of scientific models, the theoretical model must predict the performance of the physical model. Performance includes the normal functions of the physical model, plus other parameters like cost and failure mechanisms. Often in early development, the prototype and performance model will be of the same form. That is, they might both be theoretical models or both be physical models, but in any case they must be independent representations.

Engineering Development

Making theoretical models predict correctly is part of the job of engineers practicing *engineering development*. The process begins with concepts, which are mental models translated into written requirements. Good engineer practices help the engineer make most of his mistakes on paper before launching into expensive models.

Physical models with their companion theoretical models advance in stages through engineering development. Primitive physical models evolve into mature production models by stages. The initial models may be *mockups*, representing the end product physically, as in weight or form. They may be functional models, extracting energy from the environment and processing it in some way representative of the end product. The models gradually become more complex

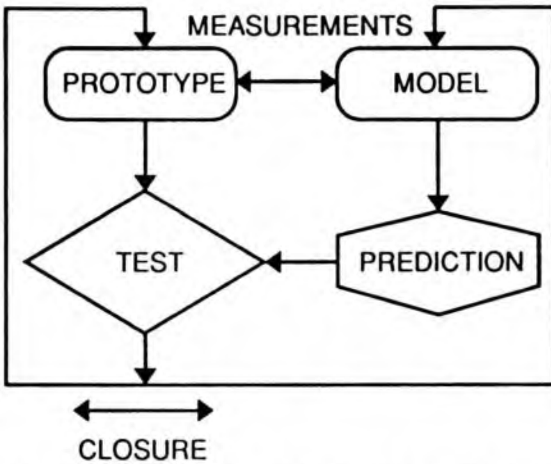


TWO BRANCHES OF SCIENCE
Basic Science
Figure 8-1L

and more representative until they are fully equivalent to the finished product.

In early phases, a development plan might ask for the prediction and demonstration of natural phenomena. For example, the plan might call for the first physical model of a focal plane array simply to produce electrical energy when illuminated by infrared light. The next model will demonstrate that the intensity of the input and output are in a specified relation to one another. These initial steps are indistinguishable from basic science.

Often the process begins with first order effects. A good model is a spring. It has a spring constant, which is the proportionality factor between the compression or expansion distance and the force applied. However, all real springs are non-linear. If stretched too far, it's spring constant ceases to be a constant. Soon, the spring will become permanently deformed. This occurs when it has exceeded its elastic limit to become plastic.



TWO BRANCHES OF SCIENCE
Technology
Figure 8-1R

This is easily demonstrated for a young class. A Slinky is a good approximation for the spring. Youngsters might even be able to make progress on this idea as purely a though experiment. "What would happen if I stretched a Slinky too far?"

Eventually it will fail by rupturing. These are stages of non-linear behavior that might yield to higher and higher orders of representation in the model of the spring.

Continuing with this spring analogy, the engineer knows that measurements of the force applied and the deformation achieved will never repeat exactly. He knows that external conditions, like temperature and manufacturing variations in the spring and its material, affect the results. So he tries to control them as much as possible. He asks the model to predict not only the average spring deformation but the variations that he will measure! Combining these, he will have reached the high order, stochastic model. At this level, his model agrees to a specified accuracy with the physical model, reproducing the probability distribution of measurements. He has exhausted the closure requirements at this level of integration. And still he is not done.

In some projects, physical models are unavailable or impractical. Examples include designs for a public utility, a particle accelerator, an epidemiological process, a spacecraft, or an astronomical telescope. In situations like these, an independent theoretical model will substitute for the physical model. A good example is a Monte Carlo[1] computer simulation of a system paired with an analytical model. These examples share another characteristic: they are incomplete examples of technology development because the objective is to make just one working model. Most often, engineering development must create a practical product in mass production. This is easy to state, but it implies some of the most difficult objectives. The product must be safe and consistent with community standards. It must yield to repetitive manufacturing at rates and costs consistent with sales objectives under the pressure of competition. The product must provide a value to the user over its lifetime that assures his loyalty.

Repetitively manufactured products include electronics, vehicles, agricultural products, and medicines. The period of repetitive manufacturing is the *recurring* phase. So engineering development projects like the remote sensing spacecraft have no recurring manufacturing phase. These projects advance directly from design, the *nonrecurring* phase, to a final fabrication phase. The absence of classical manufacturing is also a characteristic of software development. Software designs will have parallel models, but in the final phase the only thing reproduced is information stored typically on standard printed or magnetic media.

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[1]A Monte Carlo simulation produces output values with statistics, accumulated while subjecting a representation of a system to a large number of trials with faithful, random variations and disturbances.

Classical manufacturing employs a long list of processes for fabrication, assembly, and test. Some examples of processes are

alloying	assembling	bonding
casting	curing	deposition
drying	extruding	filling
filtering	forging	growing crystals
machining	mixing	packaging
painting	placing	polishing
potting	sealing	selecting
soldering	transporting	welding

Each of these has many variants. Soldering might be by hand, by wave flow, or by reflow techniques. Deposition might be vapor deposition or sputtering.

Engineers must know how each process works in terms of measurable characteristics of its output. Processes, like the products that they produce, follow progress through development stages in what engineers call *process characterization*. Engineers are continuously characterizing new processes for electronics, for example creating processes for crystals of greater purity and for solid state devices of small dimensions. These processes contribute to the feasibility of other technologies widely used in manufacturing. Some of the best examples of technology developed for manufacturing process include the applications of robotics and computers to the manufacturing line.

Engineers must know how to assure that each process stays under control during long term manufacturing. Parameters requiring control include material flow, tests, contaminants, temperatures, rates, waste products, emissions, and yields. Yield is the ultimate parameter because it measures how well the entire string of processes performs. Knowing yield means knowing the bounds on the output of the processes in measurable terms, like accuracy or purity, color, finish, porosity, reflectance, hardness, and strength. This characterization of processes is the work of manufacturing or *process engineers*. Test processes are the responsibility of *test engineering*.

Once process engineers have their processes well in-hand, then design engineers can predict the effects of those processes on a new product. This information feeds theoretical models for the first production models as well as theoretical models for manufacturing itself. As they do in the product design process, engineers will integrate low level process models upward, creating a model for manufacturing. When the theoretical flow model agrees with actual manufacturing flow, the project is at last under control and in full production. There may yet be more modeling and closure, as when the company increases the rate of production when they gain confidence or when sales demand grows.

Technology Models

Engineers plan development around a set of physical models, each with its companion theoretical model. The work involved in reconciling the two kinds of models leads to finished products in least time and at least cost. The models serve to confirm knowledge gained as development progresses. They benchmark that progress in manageable steps. This they call the process of *risk reduction*[2]. It is partly subjective, partly objective, and highly demanding of skill and engineering experience.

Because of difficulty and complexity in some projects, early models have limited scope to limit the risk assumed. As engineering development progresses, engineers modify physical models in several ways. In the earliest stages, they frequently have to make the models more sensitive and more

---

[2]Industry will speak of technology risk, schedule risk, and cost risk. These concepts convey information inside the operations. In the long run, however, all risks reduce to a cost risk. The worst kind of technology risk, a barrier which cannot be overcome, means that the project cannot be completed. The money being spent will become a write-off eventually. A schedule risk becomes a loss of business through missed opportunities, lost sales, or lost customer confidence.

stable. Later, engineers will make the physical models more encompassing, completing the set of functions until the physical models can perform a full mission.

The practice leads to naming some models according to the stages of development they represent. The models lend themselves to a useful taxonomy consisting of four major categories:

(1) Laboratory Models: principles of physics or mathematics demonstrated for first time.

(2) Feasibility Models: Optimum performance, demonstrated for eventual system application, practical improvements demonstrated, characterization of performance. While no standard terminology applies to either to industries or the field of engineering, popular terms include those in the table.

NAME	FUNCTION	FORM	FIT
MOCK-UP	NO	YES	YES
BREADBOARD	YES	NO	NO
BRASSBOARD	YES	SOMETIMES	NO

PROPERTIES OF FEASIBILITY MODELS
Table 8-1

(3) System Development Models: Full form, fit, and function demonstrated with progressive improvements in reproducibility and qualification, leading to mass reproduction. Other models include special test & qualification models, environmental models, reliability models, cost models, manufacturing process models, preproduction models.

(4) Production Models: Mass production demonstrated with progressive economic improvements. Other models include low rate production models, producibility improvement models, value engineering models, lot samples, and final articles.

The analysis of technology development above provides enough information for the layman or the student to inquire into a technology's state of development. First, ask the engineer what the planned sequence of models is. While he should be able to describe a sequence of models that he will use, he will have to help you with his particular naming conventions for the models. You might help him identify what you mean by theoretical models if your remind him that they might take the form of a set of equations or a computer model. Amplify this probing of his model plans by asking what he expects each model to demonstrate. Then ask how many of which kind of models he has built and tested, and how far along in the sequence he has demonstrated closure.

Closure

The only way engineering, or the public for that matter, can know that a model stage is successful is to demonstrate closure between the physical and theoretical models. Engineers accomplish this through testing and evaluation. The theoretical model, through its predictions, contains the criteria for deciding whether or not a stage is complete. Absence of a theoretical model creates an unproductive sink for resources, and an invitation to bury design problems. This knowledge is part of the public trust held by engineers; it is part of their professional ethic.

In basic science, closure demands that models match the Real World. In engineering development, the physical models are the Real World, but now alterable to match the theoretical model! So in practice, engineers adjust both the physical and the theoretical models to achieve closure in an iterative fashion. Sometimes failure to achieve an early goal may necessitate a redefinition of every future model, including the final article. Edison's experimentation with various filaments for his incandescent bulb before he developed one that worked is an example of persistence and the great confidence he had that his concept or model could be made to work.

Closure is validation. It serves both Science and technology, the theoretical and the applied arenas. In one sense, technology is easier than basic science because the practical model, the analog of the natural world, is accessible for modification. The engineer can adjust his Real World to bring it into agreement with his theory. This is the scientist's dream! An alternative view of the same data is that technology is more complex than basic science. Technologists must control twice the number of degrees of freedom!

Integrating Diverse Disciplines

Technology logically begins with a concept for a practical product. As the Scientific Method is not a time sequence, the logical sequence of technology development is not necessarily a chronological sequence. The creation of a new product often involves the thinking of many different people. In a complex system, it is so convoluted that it defies any attempt to draw the process on paper. It does not flow as a sequence of thoughts, activities, and events. Often the most critical part of the engineering problem is the coordination of simultaneous developments from many different disciplines.

In developing a remote sensing instrument, one group of engineers might work on a solar collector. This will be a part of the electrical power system. The objective of this group would be demonstrating greater efficiency and lighter weight for the mission. Another group of engineers might be working on light-weight, plastic optics, planned for the first time in the infrared domain. And a third group might be working on a focal plane array, the solid state sensors that convert infrared photons into electrical signals. Their objective might be to make the sensors do on a large scale what they did once in the physics laboratory. A fourth group will be designing the electronics that amplify the weak focal plane array signals, converting the energy into its color components and intensity. Other groups will be developing the software to process and transmit the signals while controlling the spacecraft. More groups yet will work on the propulsion, the telescope, the transmitters, the electrical power system, and the environmental control system.

In each area of specialization, engineers build practical models or prototypes sufficient to check against theoretical models. When they achieve closure for each segment of the project, then engineering marries the models into a larger system. They call this marrying *integration*. Each stage of integration demands a higher level of theoretical modeling to predict test results at the new juncture of complexity. This process of integration and closure continues until the final product is ready for use.

Planning and Judging Product Maturity

Staged models of technology provide the basis for a development plan. Schedule events called *milestones* demarcate the maturity of technology by stages. Each stage contains three main activities, physical model construction, theoretical model construction, and testing to demonstrate closure These activities lend themselves to scheduling and budgeting However, they are only part of the development picture.

New products may require new sources of materials, new manufacturing processes, new manufacturing test equipment and procedures, and new manufacturing flow. In a sophisticated engineering company, these sources, processes equipment, and procedures receive a treatment thoroughly analogous to that of the product. A specific plan carries there through stages, where engineers demonstrate *progressive rise reduction*, releasing them to manufacturing just in time to start the product. Progressive risk reduction almost defines engineering development.

Asking simple questions about the state of the models leads to a basis for determining the state of development. At what stage of integration or level of development has engineering demonstrated closure? If the answer is none, then the technicians are dealing either with pure research or with what the industry disdainfully calls a Garage Shop Operation. If engineering can point to the necessary Laws of Nature, a product is at least theoretically possible.

By asking questions about the plan of attack through its stages, management can set milestones for development. These plans guide the project of engineering development. They specify projects that produce models through stages of increasing complexity, scope and accuracy. They give names to the models, and assign periods for test or measurement.

These are times in which engineering exercises both the theoretical and physical models. The plan asks for more and more accuracy in the measurements until engineering can quantify the variability in the measurements. Sophisticated engineering will ask that the noise on the measurements match theoretical predictions. If they don't achieve a match, then they modify either or both models until they agree. This is iterative closure on a *stochastic model.*

So development maturity is measurable not only by degrees of integration, but by the degree of closure. At any stage, the theoretical must predict the results of physical measurements. Technology like basic science pivots on its models.

Technology Pull and Requirements Push

When technology precedes need, marketing refers to the condition as *Technology Pull.* Soy beans were a bumper crop before researchers found new uses for the product. This was a *Technology Pull.* Four wheel steering was a reality before drivers wanted it or knew they needed it. Marketing had to create a demand through advertising. Military research and development produced efficient propulsion and sensing systems. Manufacturers sold this technology by igniting a latent public desire for interplanetary exploration.

When the reverse happens, the need drives or leads the demand. This is the situation called *Requirements Push,* meaning that needs are pushing technology and science into inventions. Here engineering or marketing conceives of a product to solve a practical problem. Certainly a model of the product does not exist initially, and indeed the prerequisite science might be incomplete. Even the Laws of Nature might not be in hand.

Two examples of *Requirements Push* process are on-going projects, one from biology and one from physics. In medicine, vaccines are in demand for many diseases that exact terrible tolls on humanity. This leads to the concept. For example, consider the tropical vector or parasitic diseases of malaria and Chagas' disease. Researchers are now seeking vaccines for each disease at some point in its polymorphic cycle. They understand the concept and uniqueness of DNA in the process. They can extract proteins associated with the diseases, but they cannot specify which protein is critical. They don't know where it occurs in the DNA chain nor how to excise it. They don't know how an effective antibody might be formed. So medicine has established the concept, a vaccine, but the science is lagging. Much more work remains on the models of biological laws that govern the disease processes and a mechanism for immunity.

An example of Requirements Push from the field of physics is the need for better sources of power. In a major segment of the world's population, the only form of energy is wood burning. This form excites the U. S. environmental movements because it appears renewable. It is a so-called biomass derived from the inexhaustible sun. Wood burning, though, is not sufficiently abundant and it becomes excessively polluting.

Of course, any power source pollutes to some degree, but there are already laws against wood burning in parts of Colorado. Moreover, wood as an agricultural crop is not infinitely renewable without rebuilding the land to replace nutrients. Excessive gathering leads to deforestation and causes desertification, making restoration of the source prohibitively expensive. The conceptual solution: a low cost, low polluting, inexhaustible energy source. Examples of such hypothetical sources are common in history, from perpetual motion machines to the most recent hot flurry over Cold Fusion.

Cold Fusion is a rich field to plow for the Strategy. It is an example of a most immature technology. When Fleischmann and Pons first announced a working model, Cold Fusion was missing some Laws of Physics. Where had all the neutrons gone? The press rushed to the laboratories to spread the Great News. The Utah legislature granted over $5M of their taxpayers' money to the researchers to continue their work. They applied the political principle, "How can we not spend money on a project that could mean the salvation o mankind?" This is the evaluation model that gives infinite weight to an event of probability zero, arriving at a figure. In this case, it was $5M.

If the press corps had had the training suggested in this strategy, and no more insight into physics than it has today, they could have avoided the whole mess and prevented the waste of money. Reporters should have probed the state of model development with Fleischmann and Pons at the first press conference. What was their theoretical model? What closure had they demonstrated?

THE REPORTER PARADIGM

Reporters don't have scientific training, yet they act as representatives for the public in science matters. Right or wrong, the media convey the progress and idiosyncrasies of science and technology. They are the primary channel between the public and the science. They have an ethical responsibility to place scientific claims in front of the layman in an understandable and constructive way. They have the reciprocal problem of presenting other technical issues to the public from non-scientific sources. So they must not only probe in a responsible and complete way, but translate what they learn into the public vocabulary.

The reporter should ask the scientist, engineer, or other claimant, the following strategic level questions.

1. "Could you define your terms ... ?"
2. "You have said that a certain result occurs. What kind of theoretical model do you have? Follow-ups:
   "Is it a word model?
   "Is it a mathematical model? Does it have equations?
   "Is it a computer model? Is it stochastic or deterministic?"
   "How complete is your model? What effects do you plan to add?"
   "What past data does it reproduce? Are there any data that it fails to reproduce?"

3. "What makes your model unique?"
   "Is it like any other model?"
   "What are the competing models and theories?"
4. "Exactly what does your model predict?"
5. "Are your conclusions supported fully by the model?"
   5.1 "We can accept that the DNA is unique, but aren't you measuring the mass of large segments of the DNA molecule? Are these unique?"
   "You said that you had a DNA match between the accused and the sample found at the scene. What segments of the DNA did you measure? What were the odds for a match?"
   "Are the DNA traces from the scene and the suspect exactly the same? If so, why?"
   "How did you insure that the samples from the scene and from the suspect were indeed those that produced the traces?"
   "Was the technician expert able to point to the suspect from a large set of DNA samples? How large?"
   5.2 "Your model shows that the automobile exhaust gases are dangerous, but does your model predict when atmospheric concentrations will become dangerous?"
   "You have said that the automobile must be phased out in favor of mass rapid transit. Did your model predict the air pollution with the mass rapid transit? Did your model predict the changes that would occur in transportation demand and patterns because of the economic consequences?"
   5.3 "You said that global temperatures are going to rise. How much do you predict and when?"
   "Has your model been validated? How might it be validated? Does it accurately predict

day and night temperatures? Northern and Southern hemispheres?"

"Does your model reproduce current global temperatures? How is the climate maintained today? What does your model predict will happen to cloud cover with increased temperature?"

"What is the normal variance of temperatures expected over that time period? What is the general trend in global temperatures absent additional greenhouse gasses?"

6. "What is the order of your model?"
   "Is it a linear model?"
   "Does it include non-linear effects?"
   "Is it stochastic?"
7. "How has the model been validated?"
   "By whom?"
   "To what degree of corroboration?"
8. "Has a practical, working model resulted?"
   "Do you have a development plan?"
   "Does your plan show increasing levels of integration of physical and theoretical models with closure at each stage?"
   "Can you share your master phasing schedule?"
   "Have you estimated the cost of each step in the development process?"
   "How far have you gone in attaining closure?"

Cold Fusion is an example of a technology unlikely to reach the hands of a user. What rates as practical, the user ultimately determines according to his perception of his needs and desires. So in the end, success must pass subjective and objective evaluations by the user before the engineer and the investor know if they were successful.

The two examples of Requirements Push, the vaccine and Cold Fusion, would have their greatest impact on the Third World. Solutions to the greatest needs of humanity will come from the technology of the most developed nations. Students and teachers need to see this in perspective — technology is the solution, not a contributor, to local and global technical problems. Science education must campaign steadily against the irrationality of those who, regardless of motives, cannot distinguish between problem and solution.

Science education needs to train in judging development risk. It needs to teach the principle of comparing alternative, not absolutes, for the uses for the resources. These are basic skills for those who would hope to judge or lead responsibly.

TECHNOLOGY PARADIGM: THE ANDROID

Children come to the school system presold on science, in love with dinosaurs, space travel, computers and robots. The Strategy is to exploit these interests in new ways, going far beyond the traditional sharing and discovery. For technology training, the Android, an anthropomorphic robot with superhuman powers, is a perfect paradigm. It's potentials are inexhaustible at every age from Kindergarten through university graduate school, and not in some trivial way. It invites professional participation.

Students can use the Android paradigm to study transducers for the five human senses. They needn't stop there, for the Android can go beyond human sense bounds into magnetism and EM bands, into true extrasensory perception. Students could study the mechanical aspects of structure, locomotion, and action. They could combine these disciplines into the study of perception, with on-board computers performing as the brain and central nervous system. They could study the mission and purpose of the machine. They could study systems and integrated senses. They could study power and energy that are the food of the Android.

Pretend with your class that you are going to hire engineers and scientists. You want to tell them what you want done. Guide the class away from ideas which are too complex, such as requirements that it fly or swim. Write the ideas on the board, creating a concept and an outline of an engineering specification. As students progress through the grades, explore each technology issue in more and more depth.

> Students, suppose we were super engineers, and we were going to build a robot. What does a robot mean? How big and expensive a thing are we talking about? Let's list some ideas about its size, weight, and cost, and then list things we want it to do.
>
> Suppose you want it to clean up your room. What capabilities must it have to do that?
>
> It must see and recognize objects, so it must have color vision. It has to recognize shapes. It must recognize junk from good things, how might it do that? It must know where things belong when put away. How would it know that? It must pick things up and put them away. What actions would it have to be able to perform? To help in the exercise, imagine how things might go wrong. It could run over good things and wreck them. It could damage furniture or walls, doors, lamps & so on.
>
> Suppose it found something in your room that you hadn't planned on? Your dog! A spider. Your father's screwdriver. What would it have to be able to do?
>
> Would it have to take orders? Would it have to listen? To whom? Would it have to use judgment, listening to the right person and not doing something bad?
>
> Police have robots so they don't have to send a man into a dangerous place. What are they used for? Breaking into crack houses. Handling bombs. Entering dangerous areas, sometimes just to send back pictures. How do they send back pictures? Sometimes the police can talk to people through the robot. How do they do this? Could firemen use robots? How?

What if our robot had X-ray vision! What might it be able to do? If it had infrared vision, what might it be able to do? Does it need a sense of smell?

What might it be able to do if it could detect radio signals, including broadcast bands, TV, radar?

An alternative paradigm: design a space station! What must it have? What must it do? How might we organize the ideas? What might be the taxonomy of functions and features? For example, life support, protection, docking, communications, energy, waste, ... Invite engineers from industry to discuss the results on a visit!

ETHICAL AND LEGAL ISSUES IN TECHNOLOGY

Questions of product maturity have ethical and legal implications. A professional engineer, or equivalently an engineering firm, has a public trust to protect the public and customers against unwarranted changes in risk. Further, the engineer has a professional and lesser ethical responsibility to assure that his product meets its specifications and that it is advertised to do no more than it does. These duties cannot be met by guesswork or Garage Shop Operations. At least to these levels of trust and commitment, the engineer or business has a professional and ethical duty to create the requisite models of the product and demonstrate closure through testing or established usage. They must assure themselves and the public that they have completed the process of progressive risk reduction at least to the extent that certain forms of risk are not passed to the public or customers.

Today, the legal liabilities have much greater scope than ethical concerns. The old rules of *caveat emptor* and fault no longer apply. The business assumes an economic burden for abnormal use or even misuse of the product, and for implied warranties of suitability. The economic exposure may be proportional not to the cost to the customer nor to the public, including substantial legal fees, but to the net worth of the engineer or the firm. This is the deep pocket theory in operation. Furthermore, financial or criminal penalties may accrue for product problems arising from failure of the engineer to perform to the strictest ethical or professional standards imaginable to a jury.

POLITICAL AND ECONOMIC ISSUES IN TECHNOLOGY

American legal problems add a purely economic dimension to the professional issues. These problems present quantifiable risks, and good management can account for them in the development program and in the product pricing strategy. The process is quite amenable to economic modeling. Engineering trade-offs can swap up-front development time and money designed to reduce risk for warranty depreciation and insurance costs that cover the residue of statistically expected costs. Management can compare the results of the development cost analysis with their estimates of the external constraints, including considerations of market timing, affordable pricing, and competition. Eventually, the results provide the supporting data for strategic business decisions about whether or not to invest in products.

In today's business climate, foreign competition is especially fierce and successful. Foreign companies have a decided advantage over American firms for many reasons. The cost of money, meaning interest rates, is far lower in countries with less inflation. A lower cost of capital translates directly into a longer planning horizon and a greater number of possible new products. Foreign governments, most notably Germany and Japan, encourage business to expand and to introduce new products through tax advantages, relaxed environmental and social concerns, and less exposure to regulation, licensing and reporting. Foreign companies may actually be encouraged to adopt practices which are illegal in the United States. These include improper use of patents and trade secrets, paying foreign officials for business favors and permits, and monopolistic practices. Lastly, foreign companies have substantially less exposure to litigation for product liability[3].

For all these reasons and more, American companies require a competitive advantage in technology risk reduction. If they are going to stay in business, they need accurate forecasting and planning for development and production. They must work with parallel models, demonstrating closure through analysis and test, and maturing products in the most efficient manner possible. In the long run, they need the cooperation of the government and the media. American industry also needs some knowledge of the development process among their attorneys and juries. In short, a nation-wide improvement in science and technology literacy is not education for education's sake. It is not some vague relationship between an educated blue collar workforce and job creation. It means political and economic survival. The need for technology literacy is immediate and critical, affecting our prosperity and our way of life.

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[3]Indeed, there are other primary causes of the chronic American economic decline. A prime factor is excessive corporate debt resulting from acquisitions, mergers, take-overs, poison pills, and cash flow optimization. All of these have left companies with no margin for even minor recessions or dislocations. Another prime factor is the large scale destabilization of business caused by the fluctuations in market interest rates and inflation over the last 20 years. These are the poor results of the Federal Reserve Board, which, with the direction of Congress and the Administration, has actually been trying to stabilize the economy. These factors are but a sampling from the new science of economics which is needed to replace the social science of economics. They are beyond the scope of this book, but they are the material for a sequel.

CHAPTER NINE
SUMMARY & CONCLUSIONS

INTRODUCTION

Classical problem solving begins with problem identification, and so guides this concluding chapter. Having restated the problems lying at the core of science illiteracy in America, the chapter repeats the mission of this Strategy for Science Literacy. Following that are outlines of the problem that necessitated a honing of the definition of science. Included are the scientific method, axioms for Science, limitations of scientific knowledge, and a qualitative rating scheme for scientific models of the Real World. These constitute a formulation of the foundations of science that are vital to teachers, parents, and students; reporters, politicians, and voters; and jurists, attorneys and citizens.

Having laid the foundations, the discussion turns to the strategy for frameworks of a unified technical curriculum. The Scientific Method provides the organization, or taxonomy, for the summary itself.

The curriculum strategy offered here contains many novel principles to address particular problems. The major themes are the following.

(1) Stress English and the structure of language as the single, primary theme of Science as well as life. Command English and reading skills are also the primary objective of the recommended new Affirmative Action program.

(2) Provide a technically enriched environment anticipating developmental opportunities, checking identified mental blocks of fractions, algebraic abstractions, arithmetic operations, randomness, and graphs.

(3) Develop the intuition through experience before exposure to any theoretical concept (à posteriori basis for the à priori).

(4) Create one, integrated technical curriculum with measurements as the unifying theme.

(5) Accelerate science training by moving abstract concepts to the lowest possible level, beginning with early empirical exposure to them.

(6) Develop mathematics skills before theory through measurements and model building.

(7) Teach what Science is and its power for mankind. Teach the difference between truth and validity. Teach skepticism.

This summary of the *Evolution in Science* finishes with the branch of Science called Technology. It outlines the differences between technology and basic science, leading to a set of criteria for judging the state of technology readiness.

More than a few teachers and scientists are around today who won't qualify as practitioners according to the Strategy. A grandfather clause should welcome them to stay in the clubs but they need to learn the new tricks of the Method and teaching.

MISSION AND GOALSOF SCIENCE LITERACY

A deep-seated need for knowledge of other times may fuel man's quest for immortality. His history fairly overflows with real and vain attempts to predict. Of all the methods tried, Science is the singular endeavor that makes predictions that reliably come true, predictions about observations he has yet to make — predictions concerning both the past and the future. The consequence has been that science has created a technological society with titanic power to serve man. Science makes Man the master of his environment and of himself giving him a measure of control over the future.

The successes of science create jealousy and fear among the science illiterate. Living in a technological society, they sense that their lives are beyond their control. Dark powers threaten their belief systems about the universe and life. As they elaborate upon their beliefs, they build taller and heftier walls against objective knowledge. As missionaries of ignorance, they recruit others to join them. They preach anti-science, anti-technology, and anti-reason. They create political movements based on romantic dreams, unfazed by reality or failures, whether in the field of technology, economics, ecology, or sociology. The barriers they build are destructive to society, and all too effective from time to time.

Science is knowledge — the power to know through prediction, and to effect, to observe and to communicate through technology. That knowledge, once learned by mankind, can not be forgotten — the Planet of the Apes is science fiction. There is no returning to a simpler time. As man's knowledge expands, so does the frontier of the unknown. Progress along the path of Science and Technology is irreversible.

Science is public knowledge, which anyone can and should share. Properly framed, science literacy is achievable. That literacy must come not from detailed knowledge of the complex models of the Real World — that is for the scientists. It must come from familiarity with the elementary processes in all Science. Each person's success in today's dynamic technological world builds on his science literacy. The mission of science education is to provide individuals that literacy to cope with the Real World. Science literacy helps people in their lives as parents and citizens, where everyday issues concern scientific and technological questions. Science education teaches reasoning in an environment where communication technology provides a breeding ground for the geometric growth of nonsense. It provides the power of objective knowledge in an economic environment where technology is rapidly replacing physical labor with knowledge-based industries.

Few public school students will continue their education to become scientists, engineers, and mathematicians. A science education program geared to serve these few is too narrow. It would be unable to sustain itself politically, greater public good notwithstanding. Still, science education can serve this need for the training of future scientists quite as well though aiming at a different target. By creating the largest body possible of science-literate students, science literacy serves the individuals, it serves society, and it provides a rich pool to feed professional science training.

Science education needs to chart a new course to satisfy its mission, for the consensus is that science education in the U. S. public school system is unsatisfactory. The problem has been around for so long that is now chronic among the general citizenry in America.

PROBLEM IDENTIFICATION

Criticisms of U. S. technical education come in two distinct flavors. The first is direct — it is the general charge of low quality from about every quarter. The second is indirect, an aftertaste revealing a spoiling only under close examination; it is typified by the warfare over evolution.

Quality Problems

When experts, practitioners in the field of education and science, and prestigious societies and commissions use words like

"America ... last"
"second class status"
"must restructure ... "
"rising tide of mediocrity"
"country cannot afford ... "
"not fulfilling their potential"
" ... remains distressingly low"
"particularly critical [situation]"
"extensive and costly demands for remedial education"
"without sufficient preparation ... [for] on-the-job demands for problem solving or college expectations for mathematical literacy"

they make the case. The consensus is overwhelming that science literacy in the U. S. public school system gets a failing mark.

In industry, when a Company is in a sorry state, the semi-facetious commandment is to "Melt and repour!" Education experts and practitioners are telling the nation that our public schools are in that condition. The public demand for change is growing faster than the costs. Anything less than a melting and repouring at least in the technical curricula could lead to reform through privatization.

From industry, the dismal view of science education is fully consistent with the insiders' views. As suggested in the brief commentary, remedial education is the rule in industry. Counselors, leaders, and trainers confirm these criticisms. The industrial experience exposes a pattern of flaws in the educational background of U. S. graduates. It consists of certain mental blocks or educational deficits that individuals regularly bring with them to the work force. The problems extend as well to their personal lives. The table at the top of the next page contains an outline of these chronic problems in intellectual development, along with nominees for the hardest hit professions.

These are not simply problems with laborers at the lowest skill levels. The observations are so prevalent as to indicate chronic weaknesses in the educational system nationwide. They point directly to failures in the curricula that professional educators defend as a creed, and that the public naively trusts to the system. Ask a professional educator, and he will tell you that the problems are

breakdowns in the families,
drugs and weapons,
teenage pregnancies
gangs,
lack of parental involvement,
classes which are too large, and
salaries which are too low

DISEASE	SYMPTOMS	MOST SUSCEPTABLE
Englishosis	Inability to use English to minimum job standards.	Engineers, scientists
Determinitis	Inability to cope with randomness[1].	Degreed professionals, citizens
Integeritis	Inability to work with fractions or decimals.	Clerical & blue collar workers, parents
Enumeritis	Inability to work with basic mathematical operations[2].	Non-technical degreed professionals
Verbalosis	Inability to manipulate basic algebraic expressions[3].	Administrators, clerical workers
Graphosis	Inability to use elementary graphs.	Clerical workers, teachers, media

MENTAL BLOCKS & DEFICITS
Table 9-1

In short, the ball is not in the professional's court, and the only solution is more money. Conscientious educators have compensated for educational failings with courses designed to motivate — courses with relaxed norms that give the appearance of more students in the success column. Of course, the greatest motivator of all may be acquiring personal, practical knowledge, and building upon it from year to year. The breakdowns in education lead to one of two conclusions. Either the curricula are fundamentally at fault, or a major revision in the curricula is worth the experiment to rescue the system. Whatever educators believe about the

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[1]Deterministic thinking supplants any instinct for non-deterministic thinking. The problem occurs not just in technical matters, but routinely in business, economics, and life.

[2]Especially addition and multiplication, but extending to exponentiation, logarithms, and then to elementary functions. Knowledgable people daily misuse "exponential growth", giving it a sense of out of control expansion or limitlessness, and failing to understand the equivalence with "geometric growth".

[3]The algebraic expression that goes with "Let x equal ..." is for the eyes to roll to the back of the head.

problems in education, they need to play the game *as if* the ball was in their court.

THE AMERICAN EVOLUTIONARY WAR

Creationists idolize the theme,

> "The Theory of Evolution cannot explain the diversity of the species."

All by itself, the sentence shows a lack of understanding of the power of science. Creationists quoting this line will disparagingly emphasize the word *theory*, intoning and implying that a theory is a weakness in science. In their use of *explain* instead of *account for*, they give subjective powers to scientific theories, especially strong powers that might explain something to the closed mind. In their usual arguments that embellish this theme, Creationists seek to invalidate a scientific theory because it is incomplete or imperfect. In the bargain, they imply that having "discredited" one theory, they have brought down all of science. No one has explained to them that Science is never complete, nor that Science cannot be perfect in its models.

Creationists changed the label on Creationism to Creation Science, revealing that they don't know the difference between a scientific model and a belief. It also shows that they know how to make and use propaganda. Unfortunately, they have scored some successes with this ploy. They have managed to pollute science curricula and text books with references to Creation Science, exposing the dismal science literacy among some legislatures, administrators, and State and local school boards.

Science educators were not ready for the battle. Taking a little license with context at their expense, they over-reacted in defense of evolution and science. They exalted scientific theories. They suggested that evolution had extraordinary powers, even a will of its own to effect a plan, a direction. They doubly underscored the word evolution, misapplying it to geology and the atmosphere. Evolution is "descent with modification" they claimed, thereby implying the existence of geological and atmospheric descendants! Science educators go so far as to suggest that all three modes of evolution worked in concert. Science educators were justifying their own Conductor!

No matter whether their Conductor is Science, Random Chance, or Evolution, the inference is (a) unscientific and (b) sure to inflame the Creationists even further. The issue was and is far too sensitive for any such excesses. Scientific method demands precision of language as the foundation of science, but nothing places such a demand on proponents of belief systems. No one said that the playing field was level. Science has set its own demanding criteria to guide its practitioners, judges, and teachers.

Evolution is not a C-student among scientific pronouncements. On an objective scale, a theory is the best that science can offer today for the development of the species. Graded on a curve, as vague as the theory might be, it gets the top mark, A+. Not only does it get a high mark, it gets the only passing mark in the class; Creationism gets a generous incomplete.

Science has no bone to pick with Creationism. Science contains only objective knowledge with predictive powers; it doesn't bother with belief systems. Educators need to purge all forms of belief systems from the curricula. The purging should leave only one "ism" in the end. That is rational skepticism, the process of healthy doubting over claims for ultimate truth and infallibility from any quarter.

Science educators need a comprehensive, concise, teachable definition of Science. They need to hone their definitions to make their points. These things this Strategy for Science Literacy gives to them. They need to be perfectly clear about what they can include in the domain of science, what the scientific method is, and what power Science has in spite of being perpetually denied perfection. *Evolution in Science* provides solutions to these problem.

SCIENCE AND TECHNOLOGY IN THE MEDIA

For the first time in our lifetimes, the world is moving into a peacetime economy. Political decisions are dominated by technology issues and economic issues which should be technical but instead are relegated to economists trained as social scientists. The astrologers are running the observatory! Economists have no model with any predictive power for any economic system, much less an unprecedented robust peacetime economy.

Decades of profound weakness in science education now infect the political leadership trying to cope with severe technical problems. Drug use and AIDS are epidemics with strong but unrecognized economic components. Unemployment and bankruptcies are up and increasing with little understanding of the underlying technical causes. The national debt is threatening to consume all national income. Meanwhile business are being forced to relocate or shut down based on the flimsiest of scientific models. The media regularly reports some new environmental holocaust. The predictions of cancer, cataracts, birth defects, species extinction, and starvation increase daily with no new evidence and often in the face of contrary evidence. Unscrupulous and unthinking scientists cooperate with the media and politicians to exploit ever increasing threats in search of ever increasing grants.

The global crises of climate, ozone depletion, energy waste, deforestation, and pollution, carried to irrational extremes, are taught as science in the American classroom. No wonder that interest in science declines from first to last in K-6. Conservation has substituted for Science, and the result is most depressing. Could this be a contributor to the fact that suicide is the leading cause of death among K-12 students?

The battle cry today is that the solution to the American malaise is better education or some new form of isolationism. American jobs did not disappear because of illiteracy among workers. In fact, most job loss has been in the blue collar sector where manufacturing moved off-shore to capitalize on the cheap labor of much less educated workers. Japan is facing the same phenomenon today as their manufacturing moves off-shore, some of it even to the U. S! American job loss is also considerable in the educated, white collar sector where large numbers of skilled people with college degrees have stepped down to service and sales jobs, or are in early retirement during what should have been their most productive years. Education does not create any new jobs outside of the education sector. The idea that restrictive trade policies is a cause of American problems is equally misguided. The decline of American industry is dominated by declining domestic market shares and has little to do with restricted foreign markets. A little training in objective thinking can lead to appreciation of the Cause & Effect that operates in economics.

General Motors, the Fortune One company, has seen their once dominant market share halved by the Japanese. This has not happened because the Japanese can't buy any Chevrolets, but because the American's won't buy enough. It has not happened because Japanese cars are cheaper (they are not) nor because they are more "fuel efficient" (which they are). The Japanese are simply investing in and hence producing superior products. They are so much better that they have unseated American brand loyalty and overcome the cost of importing. Moreover, the superiority of their products is quality where quality means workmanship. Japanese cars always start and run, need almost no repairs, and rarely leak anything. Meanwhile GM is into their third decade or so of advertising that their products are superior because Mr. Goodwrench is standing by to repair their vehicles with "genuine GM parts". Could the problem be any more obvious?

The problem in Scientific Literacy is a cancer that began decades ago in American schools. It has metastasized into government and the media. It spread through the schools of education to feedback degeneratively on students. Technical misinformation and distortion feedback through the media, whether deliberate or accidental, needs to surface as primary ethical concern of owners of the press and networks, and of Americans in general. Reporters specializing in consumer advocacy stand ready to whip rare misfortunes with products or services into headline-grabbing, career-making, industry-breaking, billion-dollar liability suits. The problem is economic. It flows into a receptive legal system that feeds on juries that are samples drawn from a gullible, science-illiterate public.

So educational reform lies not in more money thrown at failing programs. It lies in restructuring of the technical fields that dominate modern societies. It is a revolution of science, mathematics, and language education as outlined in this Strategy. It can begin tomorrow in any classroom, and need not wait for the bureaucracy to catch up with the new frameworks, curricula, texts, visual aids, and equipment. It begins in the morning with Measure-See and universal demands for full command of English. In no sense is it a big-ticket item, and that may be its Achilles heal!

Education should be a primary political concern. However, the issue is not the creation of a more literate workforce, but of a more skeptical and rational electorate. Our children are being taught to reduce their expectations in a declining economy. The curriculum is teaching them to live without, as in

> shortages of everything — plastics to wood,
>   water, energy,
> mass transportation for everyone else, &
> the silly inconveniences of wasteful recycling.

The media needs the knowledge to inform the public that a drought may be an act of God, but that a water shortage is an act of man. Prosperity in America needs two things:

(1) a demand for and expectation of a greater, not a lesser, material well-being, and

(2) a healthy, responsible industrial base that provides prosperity, the world's cleanest environment, and soul-saving jobs.

The leading edge of the revolution in science literacy, though, will not be in the educational institutions but in the media. The nation needs a new awaking in media, an abandoning of ShowBiz News for a return to journalistic ethics and responsibility, especially in science, technology, and economics. GM needs a public roast where Mr. Goodwrench gets his gold watch, and television owners dressed in tuxedos should host a prime-time award ceremony to give Mr. Goodearth the hook.

SCIENCE & SCIENTIFIC METHOD DEFINED

How can science be acquired, how can it be rationally taught, if it cannot be concisely defined? Science demands precision in language, and it cannot thrive without it. The prevailing method today is to leave both the student and teacher of science to acquire a contextual meaning for science from articles with titles like, "What Science Is", and its sometime companion, "What Science Is Not". Evolution in Science tackles the problem head on, deriving a new operative definition of science.

Definition of Science

The Strategy for Science Literacy leads in the evolution of the word *science*, deriving a practicable definition for science along the following lines:

1. *Science is a branch of knowledge.* Science is not an obscure occupation, safely ignored by anyone who might, or by the intellectually lazy.

2. *Science is the objective branch of knowledge.* Science has no bounds to its domain other than dealing with things that man can define, record, measure, and quantify or order. Even these attributes will not assure objectivity, for a group of well-trained observers can fool themselves into thinking that the group has made a discovery. From early childhood, each person's senses and mental models shape his perceptions of the Real World. These models, created by his brain and imperfect as they are, are essential for each to interpret his senses. The models are

the essence of both observation and subjectivity, and they can be improved through training in science.

3. *Science is shared, public knowledge.* Objectivity, the stripping of the subjective from our mental models, comes from open sharing. Sharing mandates the least ambiguity. Openness allows criticism and growth. Sharing allows others to make similar observations in spite of their unique different subjective biases. It empowers many brains to concentrate coherently on a subject.

4. *Science creates models that account for observations of the Real World.* Science creates objective models that replace private, subjective models.

5. *Scientific models build on measurements of the observations.* Measurements, the result of comparing observations with standards, provide consistency in observations and permit the sharing of experiences in an objective way. Measurements create facts; facts are measurements. Still, with all the precautions laid down so far, a model that a scientist might create from solid facts could be nothing but myth. No matter how often he might repeat them, additional measurements can provide only improved accuracy. Science asks something substantially more of the practitioner's models.

6. *Scientific models require validation through demonstrated predictions of qualitatively new phenomena or relationships.* A qualitatively new phenomenon is one involving different parameters than those that formed the facts the scientist used to create the model.

Objective knowledge evolves like life, proceeding randomly from a settled base into perpetually new territories. The progress may be guided by the most intelligent humans on earth, but it is random because success has a large, unpredictable component. Strong theories survive, subsuming weak theories or abandoning them to die. Complex ideas build on the simple. Models flow with punctuated gradualism, like the very evolution of life included within Science. The trends are positive, and the process is irreversible. All the ignorant men working in concert cannot stuff the Genie back in the bottle.

Axioms of Science

Throughout the laboratories of the world, the practice of Science proceeds rather unimpaired by most of the questions that trouble philosophers and popular writers. The Strategy for Science Literacy recognizes the unfettered success of the rational pursuit of Science by laying down a set of axioms that serve the practicing scientists and engineers.

Axiom 0: Rational Domain. The domain of discourse lies in rational thought.

Axiom I: Axiom of Curiosity. Man must answer all questions; he craves reasons and knowledge of the future. This provides the Mission for Science.

Axiom II: Real World Axiom. There exists an all encompassing Real World beyond knowledge.

Axiom III: Cause & Effect. Each Effect observed in the Real World has a discoverable Cause in the Real World.

Axiom IV: Measurability. Every objective observation is comparable to an unambiguous standard.

Axiom V: Uncertainty. Every measurement has an error.

Axiom VI: Master Clock. There exists a master clock which is universal, uniform, and unidirectional.

Axiom VII: Axiom of Least Work. Systems that can adapt will evolve to the least expenditure of energy.

Axiom VIII: The Axioms and Rules of Logic. Science is based on logical discourse, employing the rules and axioms of logic. The precise composition of this set of axioms and rules depends on the choice of the particular scheme of logic.

These axioms deny to Science the ability to judge itself, to be a part of the Real World it is characterizing, or in any other way to participate in the distortions of self-referencing. Furthermore, the axioms recognize that Science is man's most powerful tool and need not be imbued with certainty or any other form of the ultimate.

Scientific Method

All the seeds of the Scientific Method lie within the derivation of science. As presented in *Evolution in Science*, the Scientific Method consists of a set of attributes organized into four major categories,

Foundations,
Discovery,
Creativity, and
Validation.

These attributes have a logical but no necessary chronology. Every attribute must be present in a field of study for that endeavor to qualify as a science. A complete outline of the Scientific Method appears in the table on the next page.

Foundations of science include natural language and its derivatives of logic and mathematics. These permit the expression of observations, relationships, and processes with the least ambiguity. Precision in definitions allows observations and measurements to proceed with repeatability. Mathematics, which is a labyrinth of logic and definitions and nothing else, allows science to explore the full consequences of their models. Mathematics leads science into unsuspected new territories from the mental constructs called models.

Discovery, to adapt the popular word, is the art of making observations and measurements. Measurements, the comparing of observations with standards of like objects and processes, is the backbone of science.

A. FOUNDATIONS
1. Language
2. Logic
3. Mathematics

B. DISCOVERY
1. Observing
2. Measuring

C. CREATIVITY
1. Modeling
2. Predicting
3. Designing Experiments

D. VALIDATION
1. Experimenting
2. Confirming
3. Evaluating

COMPLETE SCIENTIFIC METHOD
Table 9-2

Creativity in science is the extraction of patterns from measurements expressed as models with predictive power, the objective of science. Creativity includes the design of experiments to confirm or validate models. Some philosophers have gone so far as to demand that any theories contain falsification criteria, creating a similar mandatory link between modeling and experiment design in the creative part of the method.

Educators often overlook the strong creative element in Science. Perhaps this is an oversight, but it may be due to a belief that nature contains laws simply to be discovered. Science itself holds no such belief. The creation of models from patterns is the art of generalization and the application of the Cause & Effect Principle.

Validation is the process of gathering data and organizing them to corroborate the predictions of the model. *Confirming data* increase the accuracy and perhaps alter the scope of the data upon which the scientist has constructed the model. *Validating data* have the same effect, but upon the novel predictions of the theory.

For this Strategy, Validation extends to additional qualitative factors. These are the utility of the model, the novelty of its predictions, and its progress through confirmation and validation. Information about a model will include some of these attributes, providing a measure of quality for the model. The Strategy adopts the following categories as a natural progressive ranking for models.

1. *Conjecture*. An incomplete model or a model adapted from another domain and unsupported by relevant data is a conjecture.
2. *Hypothesis*. A model based on existing data but yet to receive any validation is a hypothesis.
3. *Theory*. A model based on existing data with supporting confirmation, at least one validating datum, and no counter examples is a theory.
4. *Law*. A model which has been validated in all possible ramifications to known levels of accuracy is a law.

CURRICULA STRATEGY

Evolution in Science integrates science curricula into one curriculum for at least K-6. It builds on a new set of themes. It draws upon the developmental skills of children, working through a program of language and measurements training to attack specific educational problems and to promote skills in the Scientific Method.

The curricula itself parallels the Scientific Method that it teaches, building measurements into models as classroom activities. This begins at the earliest opportunities, nominally Kindergarten, with graphics introduced as the model form for classroom experiments and projects. Algebraic symbols, no longer representing numbers, stand for parameters of physical objects. Iconics or picture-symbols represent logic even before the children can read.

As soon as students acquire basic reading skills, the curriculum leads them to represent the logic with symbols replacing the pictures in the iconics. These are developed into truth tables at the earliest opportunity.

The recommended early vocabulary training includes names for objects, parameters, units, and dimensions in children's immediate environment. In anticipation of receptiveness for reading, the curriculum introduces elementary etymology as signs and games with word parts. Real and fictitious dinosaur names illustrate the word roots in English.

Graphing begins with maps of familiar scenes, like the school neighborhood and the plan of the school buildings and playgrounds. Children will exploit there native skills at comparing by making measurements of familiar objects while the teacher graphs the results. The earliest experiments involve length and weight, with graphs serving as model descriptions. Measurements soon expand into temperature, volume, time, and other parameters. Elementary experiments quickly develop into compound experiments. Graphs progress into histograms. A relaxed attitude toward measurement accuracy promotes surfacing the inevitable randomness in all measuring.

Randomness also enters the curriculum with the Number Wheel, which is familiar to children through commercial games. The Strategy for Science Literacy specifies demonstrations and graphs of elementary probability concepts to keep the young mind open to non-deterministic thinking and to build upon the talent.

The idea is to teach general science as far as practicable in the K-12 progression. The curriculum provides representation for the various disciplines through projects or tasks within the measurements strand. Students can measure physical entities, life entities, and even astronomical events. They use a full spectrum of comparative techniques, measuring quantity (counting), distance or length and its kin of area and volume, time, angle, force or weight, and temperature. They use as wide a variety of standards, scales, resolutions, transducers, dimensions, and unit systems as possible.

Students learn the Cartesian coordinate system first, building an intuition for the convention that increases mean progress to the right and up. This gives them an intuition for extrapolation. Students learn to compute rates and visualize them on graphs. The rates include velocity, acceleration, mass density, population density, and frequency. Teachers demonstrate rates as graphical slopes, laying intuitive foundations as early as possible for elementary calculus. The Strategy calls upon specialists in various disciplines to augment the curriculum with representative experiments for the measurement and modeling program in their fields.

The new program begins with fifteen objectives:

(1) Prepare students from the first opportunity in the foundations of science, specifically the English language, with emphasis first on the meaning of the alphabet in phonemes (phonetics) and the meaning of combining forms in word definitions (etymology).

(2) Demonstrate the logic foundations implied in language through iconics, providing abstraction even before reading.

(3) Introduce algebraic abstractions as representation of parameters rather than the classical paradigm of abstraction of representations of numbers. This begins with labeling familiar objects with names, abbreviations, and symbols.

(4) Provide a technically enriched, non-threatening environment ready to nurture each child's mental development at his own pace.

(5) Use maps to introduce graphics, analogous to line drawings of aerial photographs of familiar scenes in the environment. Provide extensive experience with the number line by locating items on maps and two

dimensional charts before identifying the concept from theoretical aspects.

(6) Through experience in the classroom, develop an intuition for scientific precepts, especially those specific areas known to be mental blocks to scientific literacy, and to build this intuition before exposing students to the supporting theory.

(7) Promote the concept that Science is a branch of knowledge shared by all people, and not a remote practice of eccentrics.

(8) Create a single, unified technical curriculum, with measurements the common, integrating strand. Provide every classroom in K-6 an elementary science measurements laboratory. Measure and chart everything possible.

(9) Provide experience with fractions, providing conventional names, fractional addition, and the properties of real numbers (associative, commutative, additive inverse, transitive). A recommended method is to work with measuring sticks labeled in fractional and decimal notation.

(10) Conduct experiments that provide experience with and intuition for addition, scale factors, ratios, and multiplication as proportionality.

(11) Introduce random processes, using the number wheel, natural phenomena, and demonstrated errors in measurements, to cultivate non-deterministic thinking.

(12) Use the number wheel as a Real World process to provide experience with measurements and two dimensional charts.

(13) Demonstrate charts as abstractions of experiments, as opposed to the classical paradigm of the representation of equations.

(14) Construct charts from measurements until children learn how to make them on their own and how to

anticipate results (model making, interpolating, extrapolation, estimating, smoothing, and predicting).

15) Make classroom science experience a physical activity, rich in measuring and plotting.

This program breaks with tradition, bureaucracy, and contemporary pedagogy in many significant ways:

(1) English becomes the primary language of education and of science. The Strategy promotes the idea that English is the ranking subject matter training over any subject theoretically made accessible through the English as a Second Language program or bilingual education. The Strategy recommends intensive, first priority training in English, the international language of commerce, law, science, technology, and citizenship. It should be the single educational objective of Project Head Start. Make the student, not the school system, bilingual, and do so during the peak of physiological receptiveness.

(2) The definition of Science, reformulated from an axiomatic foundation, becomes the basis for the Scientific Method with predictive models at the core. The Strategy for Science Literacy establishes Prediction as the objective for Science, replacing either Explanation or Description.

(3) Scientific Method, resurrected and refreshed, yields standards for grading human inquiry as science, for grading scientific model development, and for assessing technology. It becomes the foundation for science education and literacy. The Strategy establishes Language, Creativity, and Validation as co-equals with Discovery.

(4) Measurements becomes the principal strand of early science education in a unified science curriculum.

(5) Logic and probability training begins in Kindergarten and remains throughout the curriculum.

(6) The mathematical meaning of algebraic symbols changes from number representation to shorthand notation for parameters, reducing the level of abstraction.

(7) The mathematical meaning of graphs changes from equation representation to experimental maps, substantially reducing the level of abstraction.

(8) Technology is part of the science curriculum, applying the Scientific Method with closure between prototypes and models as the avenue of validation.

TECHNOLOGY

Technology satisfies the mission of science: to give man knowledge beyond his senses, control over his destiny, and material comfort and security. It is the culmination of endless Science; it is the material fruit of Science, paralleling the intellectual fruit of Prediction.

Technology is a measure of a community's standard of living. It is the wealth and strength of nations. It provides food, clothing, and shelter. It provides health through transportation, communication, diagnosis, medicine, and treatment. It supports growing populations. It provides the knowledge that frees men from despots and slavery. Technology provides creature comforts, from boom boxes to VCRs, from sports cars to hang gliders, from synthetic leather to cosmetics. To be sure, it carries a baggage of problems, like weapons and pollution, which constitute challenges for yet improved technology.

Technology is a branch of Science, for it applies the Scientific Method to the domain of manmade objects and processes. Technology deals with two sets of models: one set is physical samples of the domain, while the other consists of theoretical or laboratory models representing the physical models. In the way that Science advances theory through validation, Technology demonstrates closure between its two sets of models.

SUMMARY & CONCLUSIONS

As man measures the progress of Science by the degree of confirmation and validation of its models, Technology maturity is measurable through the level of its models and the degree of closure attained.

Students can learn about technology through paradigms like the design of Androids and spacecraft. Educators can tailor projects like these to every grade, from Kindergarten through university graduate school. They provide insight equally into life sciences, physical sciences, and engineering. They also train the student in the Scientific Method as it applies to basic science and technology.

PROJECT 2061 RECOMMENDATIONS FOR EDUCATION

The American Academy for the Advancement of Science established more than two dozen criteria for science education in *Project 2061, Science for All Americans*. Those recommendations appear in Chapter 2 in the chart of Figure 2-2. In the spirit of measurements promoted by this Strategy for Science Literacy, the following four tables grade the 1990 California Science Framework and the education strategy in *Evolution in Science* against those guidelines in the four pairs of counterpoised tables on the following pages.

In preparing their Summary of Project 2061, the Association revised the set of themes in the main report to the four shown in the tables, and marked with an asterisk (*). These four are strongly thermodynamic in content and organization. The evolution of the Association's themes are

ORIGINAL THEMES	REVISED THEMES
Systems	Systems
Models	Models
Constancy Patterns of Change Evolution	Stability & Change
Scale.	Scale

PROJECT 2061	CALIFORNIA SCIENCE FRAMEWORK
1. Union of science, mathematics, technology	De-emphasizes mathematics; reinforces traditional barriers
2. Depth of history	Features exactly 2 scientists — Mitchell & Julian.
3. A human process	Passing remarks. Miscasts science as building concepts on subjective experiences. Miscasts scientists.
4. Residual uncertainty	Promote science as knowing, certain, and deterministic. Demonstrates poor understanding of randomness.
5. Attributes of scientific inquiry.	Neglected & avoided.
6. Mathematics	Waives requirements, downplays importance. Keeps disciplines separate.
7. Creativity in mathematics	Avoids mathematics; overlooks creativity in science.
8. Technology	Passing reference.
9. Social Impact	Promotes unscientific, radical viewpoints. Social goals weaken curricula.

I. "THE SCIENTIFIC ENDEAVOR"
California Model
Table 9-3L

PROJECT 2061	STRATEGY FOR SCIENCE LITERACY
1. Union of science, mathematics, technology	Defines technology as part of science; defines mathematics as part of language, both foundations of method. Integrates curricula.
2. Depth of history	Draws on historical perspectives — evolution, relativity, philosophy of science, Einstein, Hawking, Gödel, Mach, Darwin.
3. A human process	Major point. Serves to discriminate between the subjective & the objective, critical to the definition of science
4. Residual uncertainty	Major point. Exploits nondeterministic thinking opportunity in development. Early training in random processes measurements uncertainty.
5. Attributes of scientific inquiry.	Fully develops concept into Scientific Method — novel axioms, definition taxonomy: Foundations, Discovery, Creativity, Validation. yield theme structure for strategy & teaching.
6. Mathematics	In Foundations of science, taught relentlessly. Novel concepts — intuition before theory, new abstract orderings & meanings.
7. Creativity in mathematics	In all science. Major category of Scientific Method — model creation, design of experiments.
8. Technology	Major part of science — uses Scientific Method, parallels basic science.
9. Social Impact	Critiques radical views, promotes constructive view of strengths & weaknesses of science for citizenship.

I. "THE SCIENTIFIC ENDEAVOR"
Evolution in Science
Table 9-3R

PROJECT 2061	CALIFORNIA SCIENCE FRAMEWORK
1. Cosmic	Silent
2. Earth	Major section. Gives equal weight to physical & life sciences.
3. Physical Sciences, with major emphasis on models	Major section, but deleted references to models.
4. Life Science — Biosphere, Evolution, Homo Sapiens, Human development, Physiology, Health, & Medical Technologies	Major Section. Evolution stretched to theme, handled poorly.
5. Socio-Political Sciences — Anthropology, Sociology, Political Science & Economics	Not included.
6. Human populations	Silent
7. Technology	Almost silent
8. Language Arts, Symbols, Probability, Data Analysis, Logic	Kept distant or ignored.

II. "SCIENTIFIC VIEWS"
California Model
Table 9-4L

PROJECT 2061	STRATEGY FOR SCIENCE LITERACY
1. Cosmic	Relatively silent, but fully compatible with unified approach; examples in early measurements training.
2. Earth	Fully compatible with unified approach.
3. Physical Sciences, with major emphasis on models	Unified approach. Models cast as core of Scientific Method
4. Life Science — Biosphere, Evolution, Homo Sapiens, Human development, Physiology, Health, & Medical Technologies	Unified approach. Novel theory of evolution boldly suggested as example of mathematical biology, Scientific Method.
5. Socio-Political Sciences — Anthropology, Sociology, Political Science & Economics	Unified approach. Forces disciplines to measure up to standards of Scientific Method. Optimistic about economics.
6. Human populations	Silent
7. Technology	Major section. Part of science, it uses scientific method. Strong parallels. Closure, product maturity, dual models.
8. Language Arts, Symbols, Probability, Data Analysis, Logic	Foundation of Scientific Method. Novel, integrated, reorganized. Special pedagogy to develop intuition, eliminate mental blocks.

II. "SCIENTIFIC VIEWS"
Evolution in Science
Table 9-4R

PROJECT 2061	CALIFORNIA SCIENCE FRAMEWORK
1. Punctuated gradualism as the pattern of science.	Not discussed.
2. Great Western ideas	Not discussed.
3. Themes* — Systems, Models, Stability & Change, Scale	Seizes upon themes — backbone of new science education, but uses list selectively. Abuses, & strains application. Disclaims its own list, leaving educators in quandary.

III. "PERSPECTIVES ON SCIENCE"
California Model
Table 9-5L

PROJECT 2061	CALIFORNIA SCIENCE FRAMEWORK
1. Honesty, Logic, Evidence	Passing remarks. Naive in environmental issues, lack of skepticism damaging to students.
2. Scientific Value	Light treatment; promotes unscientific political views.
3. Objectivity	Light treatment. Promotes subjectivity.
4. Computational Skills	Underplayed.
5. Measuring	Ignored. Discusses relevant developmental skills, but misses obvious connection.
6. Communicatin g	Neglected — Reduces standards for Limited English Proficient; Perpetuates English as Second Language (ESL). Keeps language arts separate.
7. Healthy Skepticism	Promotes nonscientific ideas. Propagandizes rather than challenges.

IV. "MENTAL HABITS"
California Model
Table 9-6L

PROJECT 2061	STRATEGY FOR SCIENCE LITERACY
1. Punctuated gradualism as the pattern of science.	Not discussed
2. Great Western ideas	Not discussed
3. Themes* — Systems, Models, Stability & Change, Scale	Proposes Scientific Method as unifying, ordered set of themes. Promotes major curricula revisions, proposes unified science curriculum.

III. "PERSPECTIVES ON SCIENCE"

Evolution in Science

Table 9-5R

PROJECT 2061	STRATEGY FOR SCIENCE LITERACY
1. Honesty, Logic, Evidence	Emphasizes logic, evidence in method. Defines facts, principles.
2. Scientific Value	Promoted.
3. Objectivity	Defines science as the body of objective knowledge, develops idea throughout method.
4. Computational Skills	Promoted through development of intuition. Major emphasis: algebra of units & dimensions.
5. Measuring	Basis of models. Equated with objective observations. Backbone of early integrated, unified science curriculum.
6. Communicating	Foundation — Objectivity, Precision in language. Enlarges language program — Etymology, computer language, foreign languages.
7. Healthy Skepticism	Practiced, demonstrates reasoned challenges at every opportunity.

IV. "MENTAL HABITS"

Evolution in Science

Table 9-6R

Skepticism

The California Science Framework's repetition of ecological beliefs runs contrary to the goal of teaching the mental habits of skepticism. It is neither legitimate science nor legitimate science teaching! The Framework gets an F on mental habits for its examples of indoctrination over skepticism. Schools cannot teach mental habits by setting up a Mental Habits Curriculum, with Skepticism as a strand. Schools teach these habits, and ethics, by repeated examples.

Equity

Equity is the latest cause in the social engineering of our schools. In theory, it means expend the same amount of time, energy, and most of all, money on each of the schools. The Strategy for Science Literacy urges that the goal of education be to educate, not to strive for some vague notion of equality in the product. Instruction should concentrate on the academic values for our culture. Even if social equality were by policy a legitimate mission for education, it would be unattainable. In the long run, it will prove both destructive and counterproductive.

A recent public TV production on education included several spokespersons supporting a curriculum in Black History. However, a panel of high ranking public officials[4] did not accept this challenge as an academic problem. Is the body of knowledge, the published works, on Black History sufficient? Has the process of peer review had a chance to operate? Once the material passes all the professional tests of this type, then the information is eligible for the mainstream teaching of U. S. history and social studies. If the leadership of any ethnic group believes that it represents a distinctly different culture from the American experience, then they might emulate

[4]Including the Governor of New Jersey, the Superintendent of California Education, the commissioner of NYC public education, some Congressional Representatives and professors of education.

cultures, such as the Jews and Asian groups, who have after-school training in their cultures and values.

The California Science Framework proposes a decelerated curricula for science to accommodate Limited English Efficiency Students. (See Chapter 1.) The authors address is "historically underrepresented", but state specifically that the seven point curricula is not a separate one for limited English students. If California is adopting the recommendations of their Framework committees, the State's educational program will have two major components. First, instead of repairing limitations in English, public education will teach around the problem with programs like English as a second Language and Bilingual Education. Second, the science program, designed and operated separately from mathematics and language arts, will be decelerated statewide to norms set for the students with limited English proficiency. The result is to make the chronic decline in education into a deliberate policy and a formal program. *Evolution in Science* faces scrapping the Framework's seven point program.

CONCLUSION

If this work includes a strategic plan for education, it ends short of the design of textbooks and curricula. That is the next step for educators and other specialists. Grade-specific recommendations should appear in Frameworks, and then in curricula and textbooks. Even so, the new approach could begin tomorrow morning.

Teachers will find their job made easier. They can gain proficiency with their students in the subject matter without embarrassment. In the early years, teachers will be relieved of the role of being Mister and Madam Wizards — entertainers and empty motivators. The science classroom will be transformed into an activity period. Discovery will be insidental to participation in measuring. Motivation will come from the building of genuine and useful mathematical skills and technical intuition.

The strategy lays the foundations in the earliest years. Professionals are responsible for extending these ideas throughout the K-12 program. While the results will be immediate and obvious, the costs are relatively small. It is a road map for a revolution in science, math, and language education, but it is not a "big ticket item".

Some of the extensive work remaining includes

- Expanding on the measurements projects to include different scientific fields, and to make them progressively more advanced.
- Adding non-linear phenomena.
- Extending mathematical operations (addition and subtraction) to functions, including especially exponential and logarithmic processes.
- Adding a library of examples of probability distributions, supplementing the overworked, oversimplified "bell shaped curve".
- Restructuring mathematics, language, and logic, distributing it throughout the curriculum coordinated with measurements projects.

Do not read too much into the Strategy's use of the phrase "non-threatening" in its call for creating an opportunistic, nutritive environment. This means neither ungraded progress reporting, nor the elimination of competition in the classroom. In fact, *Evolution in Science* promotes the idea of measuring and grading individual growth during each school term. The effects of these pedagogical theories cannot be discerned from the standpoint of industrial science. On the other hand, the author is not without his conjectural model or opinion about these methods.

First, even imperfect grade reports are important to a child's motivation to perform, and to his parents' motivation to participate. They are measures, and so are fundamental to objectivity even if the errors are relatively large and the methods highly subjective. Second, competition is a major driving force for individual achievement. It produces the optimum societal progress for each citizen. This philosophy favors personal achievement over social adjustment, rejecting egalitarianism for equality of opportunity. Competition, grading, and knowledge can lead the educational system to recovery.

Except for political and economic implications, decreasing the differences between material well-being in a society is an irrelevant theory. Given a choice between decreasing the distance between the "haves" and "have-nots" and increasing each individual's material well-being, politicians often choose the former and people invariably the latter. A classless society is desirable, where classless means not one-class but a continuum of classes, a structure with material wealth distributed without a distinct class definition. A classless society is one without barriers.

A one-class society is both undesirable and unattainable. The reward for the pursuit of a one-class society is an insect-like three class society: a bloated but ineffectual political elite; an over-burdened, vanishing set of workers; and a growing accumulation of drones. A continuum of social classes provides mobility, realistic incentives for an individual to achieve, maximizing his contribution to the whole of society. It is distinctly non-Marxist. An ideal education system in the U. S. would encourage classless thinking, freeing individuals from imaginary restraints and politically motivated indoctrination.

If a major reorganization of public education is ever possible, the principle of classless organization might be ideal for K-6 or K-8. Give each child a standing profile across the curricula. Johnny was in Grade 4, now he is in Language III, Unified Technical V, Art IV, Gymnasium V.

Wherever possible, let each child or groups of children work on projects appropriate to their achievement level. At the high end of the technical curriculum, each child could be conducting arbitrarily complex, independent measurement projects, complete with graphics and analysis. This could lead to a structure of I-VI + the Continuum. A one-class grammar school, the Little Red Schoolhouse times ten, would be a most interesting experiment in the modern urban environment.

The idea might be applicable to student teams in the earliest school years. Each team would be a representative sample of the class, consisting of leaders and followers, thinkers and doers, the brightest and the "underachievers". The brightest would act as teachers within the team as it sets out on its task of measuring and modeling.

The Strategy for Science Literacy makes another break with conventional wisdom: the proper mission of the University is not the search for Truth. The highest academic standard one can set for a university is the promotion and practice of rational debate. The highest academic standard one can set for science training is the promotion and practice of rational skepticism.

The Strategy for Science Literacy makes no claim for infallibility in science. Quite the opposite: science isn't perfect and can't be. This must be as clear in the teaching. Science training must promote skepticism over all beliefs, including especially evolutionism, Creationism, and environmentalism.

In the objective world, science is all that man has, by definition. Since science is limited in certainty, in what it knows or can ever know, scientists are duty bound to challenge their own assumptions. They continuously candle the delicate eggs of scientific theories. This keeps science on the best course possible. When speaking on scientific matters, each scientist and engineer has an ethical duty to the public to reveal the standing of his pronouncements in pursuit of the Scientific Method.

CHAPTER TEN
EPILOG: A MODEL FOR EVOLUTION

INTRODUCTION

Like the Texas judge trying to decide if Creation Science could indeed be Science, *Evolution in Science* found troublesome that the available definitions of Science were either all-inclusive dictionary definitions or broad essays on "What Science Is" and "What Science Is Not". Such contextual definitions are of little use to the legal profession, or to teachers, students, journalists, or citizens. Instead, what is needed is an operative definition, meaning one that is concise and testable for the layman or the professional. This is precision in language — the first dictate of Science itself.

So *Evolution in Science* undertook the task of developing a concise definition for Science. The work began with establishing the mission, goals, and objectives of Science that would satisfy the needs of man. It lead from there to novel axioms for Science, a new structure and role for the Scientific Method, a change in the view of measurements and models in Science, and, as a bonus, a quality rating criteria for the models and fields of Science. Now the results of this evolution in the meaning of Science can be tested. Since the work began with a criticism of the treatment of biological evolution in public education, the appropriate challenge is, "How might a scientist model biological evolution in keeping with the updated structure of Science?"

As shown in the prologue, the latest California Science Framework is guilty of unscientific excesses in defense of evolution. The Framework defines evolution as Darwin's Descent with Modification, but then drifts into a vague model of evolution with a *purpose*. The Framework is not unique in this practice, for it occurs in texts and reference books as well. These authorities assign a role to species to satisfy the demands of a purposeful evolution. Evolution becomes an independent force, having a direction of its own which it somehow imposes on life forms. This is dangerously close to a deification of Evolution. Biologists speak of "mutation pressure" with the scientifically improbable meaning that the environment exerts a force on the species to change in some way. The Framework gives this property to the atmosphere, and then assigns the word *evolution* to processes in the atmosphere, the stars, and geology. It does so without modifying the definition as Descent with Modification, yet somehow retaining the overall quality of evolution as a fact. These notions are simply inconsistent with Science. Teaching evolution in this manner damages all of science education. It must be corrected, and it demands attention here.

This epilog offers an alternative in the form of a non-biologist's model for macroevolution. The result is close to what text books call Adaptive Evolution. Based on sound principles from the field of system science, the model contains elements of Neutral Variation, but with a twist. In biology, Neutral Variations are those which are neither advantageous nor disadvantageous. In the model developed here, variations are always random, and are always neutral as far as the organism might know — as if it could have such a capacity to know. The facts of evolution, though, can support many models. This one is a system engineering, strategic view of evolutionary biology. A primary objective is to use the least number of assumptions in compliance with the principles and dictates of the Scientific Method.

CAUSE & EFFECT

A primary scientific problem with evolutionary models is in the Cause & Effect implications in the arrangement of the phenomena of life, Natural Selection, the environment, and evolution. Phenomena that happen to work in synchronism, that have purpose, intent, or direction, or that require many coincidences are highly suspect as scientific models. Instead, the alternative to follow has no such assumptions or requirements. It calls upon two facts and adds one new basic principle.

The Fact of Descent with Modification

The initial assumption of fact is Darwin's historic observation.

Fact of Evolution: Species descend with modification.

The Strategy will not define evolution as this fact. Instead, it leaves evolution as a vaguely understood concept because the word carries so much baggage from decades of abuse.

The second fact is of more recent origin.

The Fact of DNA

Life exists at all thanks to the self-replicating, fault tolerant molecule, DNA[1].

Fact of DNA: DNA is a self-replicating, fault tolerant molecule that accounts for life on earth.

This key molecule, DNA, resides in a life-support cell. This cell is a mechanism that services the replicating process with matter and energy. The copying machine, DNA, mutates both qualitatively and quantitatively, both successfully and unsuccessfully. Its code will undergo changes within the basic organization of the molecule, but the molecule itself will from time to time sustain structural or organizational alterations. It changes spontaneously, as in cross-over during meiosis, or under external influence, as in mutation induced by electromagnetic radiation. Each such change is an Effect, with or without a Cause known to science today. DNA plays the key role in the reproduction processes, and demonstrates a wide latitude for faults anywhere along the steps of the reproductive process. However, DNA need not be unique. Other molecules could exist with the same property.

Principle of Opportunism

Science prefers the model with the least number of assumptions or independent causes. So the next step is to hypothesize a single, unifying, scientific principle for evolution:

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[1] Some of the rare and lowest life forms may reproduce on the basis of RNA alone. For convenience, the discussion is limited to DNA which dominates life forms on earth.

Principle of Opportunism: Life is perpetually, blindly changing.

Since Descent with Modification is a fact, and since a known mechanism for supporting genetic change is also a fact, this principle adds only the notion of spontaneity, a collection of Effects with no known Cause or Causes in the evolutionary process. This principle will prove sufficient when added to other principles, like the Laws of Thermodynamics.

Adaptive Radiation

Life is thus opportunistic, moving into new territories, new adaptive zones or niches. This principle incorporates part of what biologists call *adaptive radiation*. Life physically migrates into new territories on the periphery of its geographic domain, or the winds and tides carry life forms to the limits of the globe.

Life is opportunistic, indiscriminately launching new varieties, subtle to monstrous, to compete or not with existing forms for sustaining resources. Of the many life forms created this way, few manage to survive. This is consistent with the evidence, for life is rich in random genetic components. It exists today with frequent mutations and with great diversity.

Mutations

Life experiments with new forms on a time scale not always perceptible to man. The environment may randomly cause these new forms, not by presenting a new opportunity, but through physical intervention as when a stray particle or chemical causes a mutation. Mutations occur both spontaneously and under external influence. Spontaneous mutations, the default category, is synonymous with random, meaning science hasn't as yet modeled the cause. Many external causes are well known, but the occurrence of these agents is again random, as in naturally occurring chemicals and radiation in the environment. Sometimes the quest for the Cause is simply pointless. If it were known, for example, that a mutation began the class of mammals as a result of an alpha particle, what difference would it make if came from a recent earthly decay or a supernova eons ago?

Mutation on the most obvious time scale are those seen in colonies of Drosophila melanogaster, the common fruit fly. By the principle assumed, life is continuously experimenting without the presumption of an outside influence. Perhaps the human flu virus is an example of such continuous mutating. The human host manufactures effective antibodies, but the victory is only temporary. A new variant arrives within a year or so to probe the retired opportunity.

Recent discoveries reported in the genetics of myotonic dystrophy challenge the very meaning of *mutation*. Previously, mutation was the only model for change in the genes. It occurred rarely in these otherwise highly stable segments of heredity in DNA. Now the model for certain genes includes not only generation to generation changes, but changes that follow a pattern of growth. However, this is fine structure in genetic change below the scale of the proposed model for macroevolution, and the model itself accommodates all kinds of change.

Diversity

Diversity is widespread in both static and dynamic modes. It appears in the large numbers of life forms and species, and among individuals within some populations. Diversity occurs from random pairings of chromosomes during sexual reproduction. Initially, chromosomes themselves are highly varied when the gene pools are large. Then cross-over causes the chromosome composition to vary during meiosis.

Life defies universal declarations. A counter example exists to almost any generalization a biologist can imagine. Some genes are discretely recessive, and some are dominant. Yet sometimes inherited characteristics are blends. Most genes are stable during inheritance, but some mutant varieties show evidence of growth patterns each generation. Sometimes reproduction is asexual and sometimes bisexual.

There is both monoploid and diploid cloning. There are rare instances of polyploid configurations, as if life were experimenting with trisexual or higher order group encounters!

The Opportunistic Principle is sufficient to account for our presence on Earth, enabling us to exist to observe anything at all! The Principle puts life constantly in flux on all frontiers, unbound by rules in most any conceivable way. The process is random, but random in the mathematical sense and not in the way implied by some biology text books and some educators. The latter will use random as meaning the absence of any information, equivalent to the state of maximum entropy. Colloquially speaking, this kind of randomness means completely unpredictable, as in the toss of a fair die. However, a loaded die is equally a model of a random process if there is any chance, no matter how small, of more than one outcome from a toss. In the formulation of the Principle of Opportunism, life may try to replicate itself exactly, but in fact takes on new forms with some unknown probability. Life is a loaded die, but this principle tells us nothing of the distribution of the random process. The probability of any particular variant is not available with our present state of knowledge.

Probability Distribution of Variations

Because of the size of the code in DNA, the number of possible variations is exceptionally large for mere human calculations. Add to this the capacity of DNA to change its own length, to switch segments on or off as they code for proteins, and to reorganize into different numbers of chromosomes. The number of possibilities, though stubbornly finite is staggering. To any reasonable scale, *Evolution in Science* argues that the occurrence of genetic attributes approximates a continuous probability distribution.[2]

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[2]Meaning that it is arbitrarily close to a continuum.

Growth Rate

If a variant of a species is viable, then its growth rate is positive. Viable thus means that some individuals will survive to reproductive age, and will find a suitable mate[3] to propagate the new feature. Suppose biologists could estimate the probability distribution of each genetic variation. The argument is that the growth rate of the variant depends upon this probability[4]. If the variant is non-viable, then its growth rate is negative. Because of the extremely fine structure of variations, that is, because the variations are for all practical purposes distributed continuously, the chances of a zero growth rate are zero or at least vanishingly small. In other words, for all practical purposes, no variant will produce exactly one offspring per individual lifetime, absent external influences.

Note that growth rate is the rate of increase of the total population, the body that consumes resources. It is the net of the birth rate less the death rate. No conclusion in this model depends exclusively on the reproduction rate. From this argument, all surviving species have a positive growth rate. This means that the number of individuals in any real population inherently grows exponentially. This was one of Darwin's major observations, and is confirming of this model.

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[3]In this model, the chances of finding a suitable mate to create a new species seems too unlikely to account for speciation. No attempt has been made to estimate such chances. However, another possibility exists. Is it possible that speciation occurs when a transitive variety vanishes? The idea is that A can mate with B, B can mate with C, but A and C cannot mate. Later, the variety B becomes extinct, leaving A and C as distinct species. The first triad defies the definition of a species. The idea is that life forms do not have the mathematical property of transitivity.

[4]In Probability Theory, this is a "joint probability", meaning that the event is actually composed of more than one event. In this case, there are two events: surviving to reproductive age and finding a suitable mate.

Natural Limit to Growth

So any population will grow until it reaches a natural, external limit, for all things known in the universe are finite. A species will eventually run out of food or nesting grounds, for example. Eventually, steady state will come to pass in one form or another. Most variants achieve a maximum population size, although with secondary fluctuations. Some species might destroy its own habitat, and it will slip into extinction — like a lethal parasite so successful that it infected all the hosts.

Two variants can simultaneously occupy the same locus and achieve their independent steady state populations. The niches for the two variants overlap at least geographically. The Strategy will show that the critical parameters governing the size of the populations must be unique. Two species might eat the same, abundant foods. One species, though, might run out of caves for Winter hibernation, while the other might be limited by the number of birds that check the death rate from parasites.

However, if a single parameter is a governing resource for two populations, then the populations will eventually be in competition. The total population for the two will reach some maximum as that parameter can sustain, even if that maximum happens not be unique. This is a mathematical, not a biological, consequence. In more complex situations, the argument applies as well to a set of parameters.

Steady state in a population means that the number of individuals has no mean trend. Achieving steady state implies that the population has a unique niche. Populations appearing to occupy the same niche cannot be in steady state[5]. This is analogous to the balancing of a cone on its tip. If the assumption of steady state is correct, then biologists should look for some difference in niches when two

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[5]A mathematician would say that they can both be in steady state with probability zero.

populations seem to occupy it simultaneously. In general, the niches should not be subsets of one another. Another possibility which seems quite probable, but which is not included in this model, is that growth rates are neither constant nor linear. In such a case, two populations might exhibit a sort of resonance, alternating the state of maximum growth rate from one to the other. The change in growth rate for a least one variety or species should be inversely dependent on population size.

Biologists need to measure growth and reproduction rates while looking for environmental factors or population parameters which influence those rates. If two herds graze the same lands, migrating over the same paths, then food might not be the limiting parameter. One should find a surplus of food in such an instance. Suppose that a disease, parasite, or predator limits the size of only one population and so favors the survival of the other population that it doesn't affect. Then there must be a counterbalancing limitation on the second population which does not limit the first. This is the essence of the meaning of different niches.

Conversely, declaring that a niche is at capacity implies that no more individuals can occupy the locus represented by that niche. This has a direct translation into mathematics, and the consequences are significant. Mathematical models are not substitutes for the Real World, nor are they independent of the prose models that they quantify. The mathematical model leads Science into new consequences and implications of the model which might be invisible in the natural language statements of the model. A hypothetical situation can illustrate.

Puffins & Gulls on a Hypothetical Isle

Suppose puffins and gulls compete for nesting space on an isolated, one-acre island. Further, imagine that a pair of puffins needs one square foot to nest and a pair of gulls needs 50% more space. The acre will hold 87120 individuals if they are all puffins, and 58080 birds if only gulls. The maximum number of birds that the island can nest varies linearly between these two values depending on the relative proportion of the species. However, the trade-off is 3 puffins for 2 gulls. Therefore, the island holds a maximum of 87120 puffin-equivalents, where a gull is the equivalent of 1.5 puffins!

Assume that the island at some time becomes saturated with N_1 puffins and N_2 gulls, where the corresponding number of puffin equivalents is V_1 and V_2. [Note that $V_1=N_1$ and $V_2=1.5 * N_2$.] One more supposition, and the formulation of a most illuminating model is complete. Suppose that the average puffin produces g_1 viable offspring, and that the corresponding parameter for the gull is g_2. After one nesting season, the ratio of puffins to gulls, in terms of equivalent puffins is

$$\frac{V_1'}{V_2'} = \frac{V_1 * g_1}{V_2 * g_2} = \frac{V_1}{V_2} * \frac{g_1}{g_2} \tag{10-1}$$

In terms of numbers of actual birds, rather than bird equivalents,

$$\frac{N_1}{N_2'} = 1.5 * \frac{V_1}{V_2'} = 1.5 * \frac{V_1}{V_2} * \frac{g_1}{g_2} = \frac{N_1}{N_2} * \frac{g_1}{g_2} \tag{10-2}$$

So the result is the same, represented as the number of equivalents or in the number of birds in the each population. The ratio of birds after the nesting season changes by the ratio of their viable reproduction growth rates, g_i. This ratio operates season after season until the slower breeder has less than one pair surviving, and vanishes from the island (or the EPA comes along and captures the last few for a breeding program!)

As modeled here, the growth rates, g_i, yield an exponential growth rate for each species. For a more information on population genetics, see, Appendix C, Biology Mathematics.

Transition Species in the Fossil Record

This adaptive model can account for the troublesome fossil record, which is infamously poor in transition species. First, observe that the record is not a continuous sampling. Random, aperiodic geological events create fossil collections, as when a landslide precipitates flooding to create a sedimentary layer, a volcano lays down a layer of ash, or relative sea level falls to strand life in mud. Thousands to billions of generations might lapse between the laying of strata by these geological events. This timing of large numbers of generations between events is key to the argument. When sampling events do occur, chance favors life near steady state with stable populations. In fact, the geological event may actually precipitate the extinction, so that transition species would be most prevalent many generations after the event.

Following a large scale extinction, populations are reduced in absolute numbers and relative to the resources that support life. This opens the laboratory door, allowing variants to propagate. It could allow them time to branch into even more robust forms. Small populations also increase the chances for inbreeding, increasing the likelihood of the manifestation of recessive traits. A massive extinction thus creates two distinct processes that increase the chances for speciation. Not only does it shut down the closed-loop controls on species in competition, but the chances of a variant increases because the size of populations is smaller.

Radical changes in the environment also change the optimization point for speciation. A previously dominant form may have flourished because it became efficient in a certain saturated environment. Useful attributes that allowed a species to transition to its steady state condition become useless baggage. The principle of least work causes these features to atrophy, and the species become less robust.

By the one Principle of Opportunism, life has no memory as to form or success.[6] It has no way other than chance to recreate

---

[6]DNA may contain just such a memory. Portions of DNA in some species are known not to code for any proteins in the phenotype. These segments are likely obsolete code.

a useful structure or behavior. Moreover, it has no way to sense what will be successful in the new environment. A new form may be less efficient under saturation, but when it doesn't have to compete for sustenance or shelter, it may be the superior form.

So the adaptive zones, if they contain any life at all, will saturate with a single, stable population. The opportunistic life principle will continue to operate, gradually producing slight improvements in the population.

Stabilizing Behavior.

The Principle of Opportunism is a statement about Cause & Effect, not about the rate of change of life forms. If the Principle of Opportunism operated too easily, species might never develop to occupy any niche. Some stability is needed in the DNA and in the species resistance to variations. By this model, the mating rituals of many animals may be necessary to stabilize the variations that occur too readily in the genetic processes.

Populations struggle against the Opportunistic Principle of Life through a variety of techniques. Examples include destruction of weak members of a litter, and male combat over territory and mating privileges. Assortive mating through reproduction rituals accomplishes the same thing through a pattern called racism in civilized humans. These are controlling parameters in what constitute self-imposed niches.

NATURAL SELECTION

Consider what happens when the gulls and puffins return to the nesting ground next season. If the availability of nests is unbiased between the two, then each population will be reduced by the same factor. In this situation, the ratio of one bird to the other will continue to favor the faster breeder as it did before the population of the island saturated. If one bird has an additional advantage over the other under saturation, new growth rates will take effect. In either case, whichever bird has the greater reproduction rate under saturation will survive and the other will become extinct. This is *Natural*

Selection, a process that likely ranks as a Law under this formulation of a Theory of Evolution.

Theorems of Natural Selection

Two simple theorems support the theory of Natural Selection. First, assume that an average natural growth rate affects each population's size. Natural growth rate means having no external influence; it is the open-loop growth rate. Further, suppose that this average measured across species and varieties has a continuous probability density. The assumption of continuous distribution poses no conceptual problem. Moreover, without loss of generality, growth rate is bipolar, which means it can be positive or negative.

The following theorem is mathematical:

Theorem: The probability of a zero average growth rate for a species is zero.

The proof follows immediately from the fact that the probability that a continuous random variable takes on any exact value is zero[7].

The next theorem is a statement about the closed-loop growth rates of species.

Natural Selection Theorem: If two populations saturate a niche (adaptive zone) and compete for survival there, then either they both have zero growth rate, or the growth rate of one is positive and the other is negative.

The proof, which is trivial and obvious, depends on the assumption of saturation[8]. Generalizing to multiple

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[7]Mathematicians call this a set of measure zero.

[8]Let V_i be size of the i^{th} population, and a_i its corresponding growth rate. Since the population, V, doesn't change in time,

$$V = V_1 + V_2 = V_1{}^*(1+\alpha_1) + V_2{}^*(1+\alpha_2)$$

from which $V_1{}^*\alpha_1 + V_2{}^*\alpha_2 = 0$.

competing forms saturating a niche, at least one variant must be non-viable closed loop. For example, if six varieties occupy one niche, the slowest growing of the six will be in decline. If its decline in population is fast enough to make room for the growth of the other five, it will be the only one in decline. Once this weak sister dies out, the next weakest form or forms will take its place. The process continues until only once species occupies the niche. Furthermore, only one species will occupy a niche in steady state or the population will oscillate exchanging growth potential with another species. In such a case, the growth rates have to be non-linear. These are mathematical considerations of the word *saturation* and the concept of a growth rate, augmented with a little probability theory.

By this theorem, species with a negative natural growth rate are not viable, as one would expect. These species will become extinct, barring some peculiar environmental support system. Surviving species will all have positive, non-zero natural growth rates. This is the equivalent of an exponential growth rate, meaning that in time the population would reach any size. It grows without bounds. Populations thus grow to fill the adaptive zone. Adaptive zones can have only two steady state conditions: empty or saturated!

The Natural Selection Theorem implies that a weaker variant, even though it may be open-loop viable, will not propagate unless there is a surplus of resources and a defense against threats. It can survive only so long as the strong variants do not expand to saturate the niche. In a saturated environment, only the strongest variant remains viable. To be perfectly clear in these remarks, strength and weakness, above, or superior and inferior, below, refer only to relative growth rates. Survival of the Fittest means Survival of the Most Prolific.

Since the populations V_i are positive, the a_i must have opposite signs or both be zero.

Coupled with some basics of probability theory, the implication is that large populations become stable. Competition under saturation snuffs out inferior random wariants, given enough generations. Superior variants will replace previously dominant variants. As the probability for improvement becomes smaller and smaller, succession of forms will become less and less frequent. Perhaps the maturity of a species, determined by its rate of variation, could yield a statistical biological dating mechanism!

This version of the Law of Natural Selection applies equally to wariants within a species as it does to competing species. If the variant is the product of a dominant allele, the take-over is exponential, as it is between species. If the variation is due to a recessive allele, the process is slower but the result is the same. For more discussion, see Appendix C, Biology Mathematics.

Suppose the puffin is the sole survivor on the hypothetical island. Further suppose that a random variation of the puffin arises with an advantage. It might simply breed faster, or, more subtly, it might be better equipped to earn a nest. For example, the new variant might fly faster and get back to the breeding grounds a little sooner than the parent population. All other things being equal, this new variant will come to dominate the population and then to become the only variety surviving.

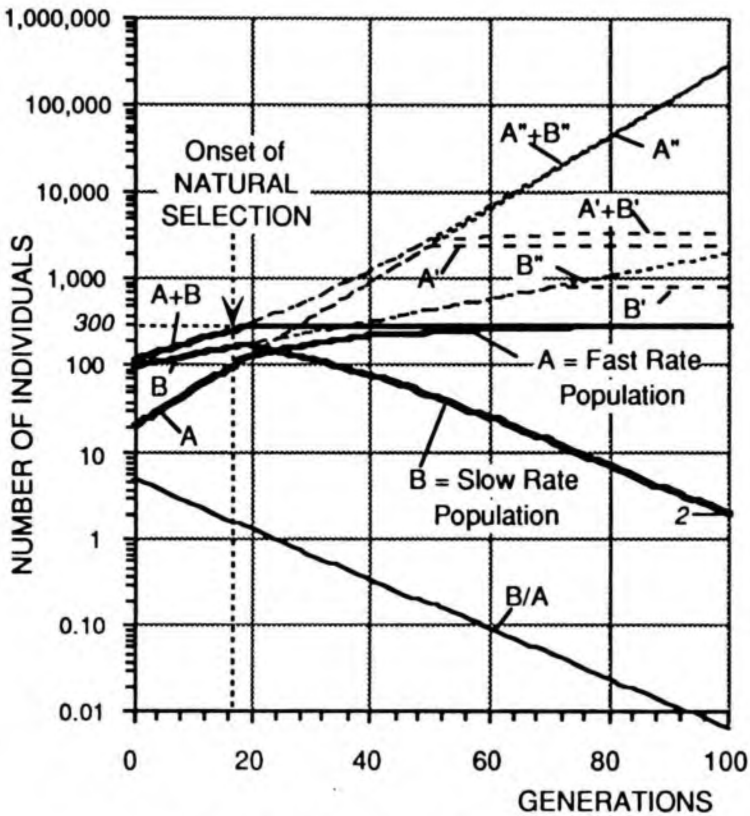
Gradualism

Underlying the statement above about the probability for improvement is an assumption about possible genotypes. Since nothing in nature is infinite, the length of the molecule and hence the number of DNA codes must have a mathematical limit. The number of species and variants is incredibly large compared to human experience, but it still represents a finite inventory of possibilities. As life changes under the Opportunistic Principle, Natural Selection works against the inventory to find fewer and fewer closed-loop viable variants.

This analysis constitutes a heuristic proof of ***gradualism*** under saturation. It indicates that experimental variations or species will propagate and modify only if they are naturally viable and the resources, including defense mechanisms, are available. It means that a surplus of all resources coupled with a low probability of falling prey creates a laboratory for experimental variations. Under such conditions, less viable species can exist and become robust through continuing opportunistic mutation.

This evolutionary process means that in the Gull and Puffin thought experiment, one species will become more and more closely adapted to the island. Is it a superior variant in some larger sense? Science can't tell without an external criterion. Under the assumptions, the chances for a variant to be more viable are slim indeed, but the changes lead in one direction. Evolution does have a direction — a population under saturation will become ever more finely attuned to its environment. If the environment varies widely enough over the span of a number of generations, the species will remain robust. Otherwise, the species will be delicate. Under conditions of a relatively constant environment, viable genetic changes will become less and less frequent as the finite number of improvements within the genetic code are randomly exhausted. Thus the Opportunistic Principle supports Darwin's gradualism when niches are full.

The chart below shows two populations, A and B. When the counting of generations begins, B has 100 individuals and A has 20. The open-loop growth rate of A is about 10% per generation, enough to reach exactly 300,000 individuals in 100 generations. The growth rate of B is a fraction above 3%, just enough to reach 2000 individuals in the same period. Curves labeled with the primes show how the populations would grow to their individual limits, (A to 2500 and B to 800). The double primes indicate curves with no capping whatsoever. (The numbers are all arbitrary, selected to illustrate the effects distinctly on a single chart.) The Natural Selection presumption is that the niche can support only 300



NATURAL SELECTION

Figure 10-1

individuals. At this point, the relative growth rate of the two populations, shown by the line B/A, stays the same. However, enough attrition occurs equally to both populations to keep the total population fixed at 300. The result is that the faster breeding population, A, takes over and B heads for extinction in exactly 100 generations. At the 101st generation, B has fallen below individuals. Poor B! A perfectly viable species, robust enough on its own, is driven to extinction by another species it might never even see. Population A need only be more prolific.

So the model shows that the single Opportunistic Principle results in Natural Selection. Moreover, populations grow without bounds until a resource becomes limiting. Furthermore, absent a controlling parameter, species experiment with marginally viable and widely different variants Weak variants are free to reproduce with random losses to the environment, predators, and disease, but avoiding Natural Selection until a controlling parameter comes into effect. If enough changes come to pass, interbreeding will become impossible. The life form will have created a new species. As resources come into short supply, the new species will begin to optimize to its niche, or start its march to extinction.

Speciation & Punctuated Equilibrium

Thus the Opportunistic Principle accommodates *speciation* whenever resources are plentiful. This implies that speciation would be a mode following major periods of extinctions. New species will bloom because of the temporary surplus of resources left by the decline of the previously established species. Marginal species will survive to develop strength. The Opportunistic Principle, therefore, contains a natural consequence of *punctuated equilibrium*. Moreover, speciation and Natural Selection alternate. One or the other is in effect, and this conceivably this could occur at any level in the taxonomy of life.

IMPLICATIONS OF THE THEORY

Natural Selection is a mere opportunity to survive or a denial of such an opportunity. Natural Selection plays a role in the process much as hills and valleys do in the formation of lakes and rivers instead of wetlands. The environment thus shepherds or marshals life. As easy niches fill, life becomes more specialized to occupy the narrowing windows of opportunity. A direct result of the Opportunistic Principle and Natural Selection is that life is *genetically adaptive*.

Adaptation suggests another, qualitative way to judge maturity as species approach steady state. The existence of highly elaborate behaviors and defense mechanisms, as in mimicry, could be the exploitation of a highly specialized niche.

Controlling Parameters Switch Natural Selection On & Off

Suppose that a species has come to steady state in its niche. Steady state means that the population no longer exhibits any long term trends, and implies that Natural Selection is operative. Suppose further that the controlling parameter in the environment is a predator. Now if a random variant were suddenly to appear that had a greater advantage in, say, its defensive coloration, then it would function in a new niche if the advantage were great enough. Now camouflaged against the threat, some new controlling parameter operates to limit the ultimate population for this variant.

In this thought experiment, the loss of the old controlling parameter switches Natural Selection off. The population of the new variant will swell and other species will be free to enter the niche. This new niche, of course, includes a certain coloration. The new species must have that coloration to exploit the environment, so success invites mimicry. Several competing species may all have the same coloration, but because they are otherwise different, they may now occupy different niches. Each might have its unique controlling parameter.

The controlling parameters are like dams in a stream, creating Natural Selection Lake, and the water is life. When a species finds a way around the dam, it flows rapidly and randomly, meandering until it gets trapped in a different Natural Selection Lake. It might join the path of other species, or it may have the power to cut a new path, opening the way for yet other species to follow.

Ever Increasing Efficiency

This theory demands that species become ever more efficient. A species absent threat of disease, or drought, or low food supplies will lose resistance to these inevitable phenomena. Because environments change on Earth, species must have a reservoir of power within their gene pool or behavior repertoire to adapt to the environment. *Canalization*, which Encyclopedia Britannica defines as "resistance to further environmental changes", will occur as long as the environmental changes are frequent enough to test the species. This is the sustaining of adaptability in the phenotype. It is woolly coats in Winter, and thin coats in Summer. It is as elaborate as lower species that employ parthenogenesis[9] during feasts and bisexual reproduction in stressful times. However, any excess capacity becomes a burden to the species under saturation.

A principle of least energy or maximum efficiency applies. A species or a variety will develop just enough margin to survive. It will have a reserve to handle variations in its environment, like heat or cold, flood or fire, feast or famine, or the variations in other living things that prey on it. Anything else leads to extinction. Excess capability, though, is statistical extra baggage that atrophies. Random changes in the genotype which are more efficient will replace those that cost more energy. These ideas, coupled with the principle of least work or maximum efficiency, account for the species becoming more and more specialized, more and more complex, and on the margins, more and more fragile.

Evolution to More Complex States

Some biologists have concluded that evolution to more complex states cannot be a trend. The ability hypothesized for DNA to tolerate mutations, to grow in code length, and to retain unrealized code[10] specifically allows this molecule to evolve into more complex forms (where complexity naturally means code length). A mathematical theorem is lurking here that says increasing complexity is the mean for this kind of random walk.

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[9]Asexual reproduction.

[10]I.e., code not appearing in the phenotype.

So life has to be adaptable because environments change from time to time. Did life on earth just happen to have within it a reserve of adaptability for sudden changes in its environment? This is improbable. If science postulates that at some time past, life forms existed both with and without this reserve, then changes in the environment would have left us only the robust varieties to observe directly. The theory of adaptation does not demand à priori that life be robust against environmental changes. Instead, the theory admits that previously non-robust forms could have existed or might yet from time to time evolve. Non-robust forms were, are, and will be doomed, because the environment does change. The record is clear that global climate and vegetation changes occur. Land masses once submerged are now near the peaks of the Himalayas, and territories once populated with land animals lie now submerged under lakes and oceans. The carbon dioxide content of the atmosphere has varied over the millennia, perhaps on a scale greater than man could ever effect.

These considerations lead to the conclusion that if the environment undergoes a prolonged period of small variations, life will become less robust. A drought is not an absolute condition, it is a situation for which life is ill-prepared. It is a state sufficiently outside of normal parameter ranges to stress life.

Suppose the temperature on earth were to stabilize for many generations, varying between, say, 70 and 78°F, night and day, and all seasons. Then the theory would predict that the species would loose their ability to survive outside this range. The consequence of a return to formerly normal conditions would be mass extinction.

Extinction of the Dinosaurs

Long periods of geographic and atmospheric stability precondition life for mass extinctions. The long endurance of the dinosaurs might have been precisely a consequence of exceptional stability in Earth's environment. If so, then the animals would have become narrowly adapted through specialized functions, behavior, organs, and even chemistry. The consequence of this model is that an event as cataclysmic as a massive asteroid collision by today's standards is not necessary. The degree of change required to precipitate a mass extinction is just slightly greater than the extreme fluctuations experienced by the species over the past thousands of generations.

By the Opportunistic Principle, life is constantly but blindly trying to move into voids on the periphery of its environment (adaptive radiation). The process resulting from the one principle accounts for diversity and variability in their many forms. It accounts for bisexuality, the resulting large gene pools, roving males, and selective behavior as in mating rituals.

> Sex is one of the great paradoxes of biology. Since thousands of plants and animals multiply asexually, why do so many other species undergo the risky, time-consuming process of sexual recombination? James and Carol Gould show how the diverse mating practices of species may account for behavior and physical differences between the two sexes and ensure a species' evolutionary success.

This question from a brochure advertising the Scientific American Library seems to have been answered. By effecting large gene pools, bisexuality provides diversity at the species level. Bisexuality, though, protects against a potentially dangerous form of diversity; it provides life with a decided and perhaps measurable tolerance to mutations. One cannot say what the relative frequencies are of externally caused mutations and so-called spontaneous mutations. However, mutations must occur much more often than do threatening environmental changes. Otherwise, Science must adopt another principle to account for coincidences between mutations and major environmental changes. A consequence of the simpler model is that extinction of species and varieties is an on-going, natural phenomenon.

In adaptation, randomness is a prerequisite. It is not an accident — a deviation from the path to some goal of nature or God. When scientists look at their measurements, they systematically remove the variations called noise to uncover the signals, called patterns. In the development of the species as in other sciences, the signal may well be that noise! That is, the robust species are those that randomly develop variants.

The record of life forms is, in one sense, *evolution*. It is a random walk, implying that each change builds on the previous manifestation. It is unpredictable, except to say that small changes are much more likely to succeed than large. Unpredictability in evolution in no way means that science cannot learn more about it. The random walk character only means that man does not yet know how to predict yet unexpressed life forms. A baseball team playing 700 ball for a season follows a random walk on its way to the pennant.

Biologists might establish from this one principle that if an ecosphere can support life, it will — in one form or another. Volcanic islands suddenly come into existence, and quickly become host to a variety of life forms. If an area of earth were temporarily sterilized, life would reoccupy the area through any number of mechanisms. If genetic adaptation is probable, expect it in the lowest life forms. The region around Mount Saint Helens is a modern laboratory that closely fits this model. Surprising bacteria forms are now apparent there alongside young plants whose seeds or spores were carried into the area by birds or the winds. In the evolution, each life form creates an environmental opportunity for other life forms.

Under the Adaptation Theory, evolution is not a driving force; it is not even the fundamental principle. Opportunism is the fundamental principle of this model, and evolution, the historical record, is the consequence. This is an alternative theory, based on and consistent with the identical set of facts as that propounded by biologists. Instead of the miracle of evolution with its predictable direction, one has the pragmatism of opportunism with adaptation as a consequence. Natural Selection, too, is not a force working on life. The environment neither significantly alters genetics nor is it coordinated with evolution. In this view, adaptation leads to evolution, not the reverse, making adaptation the more fundamental concept.

Furthermore, Adaptation Theory need not require the release of a reserve power of adaptation, triggered by an environmental accident. Genotypes need not have sensing mechanisms, although phenotypes must. Instead, the theory says that life is opportunistic, continuously changing and that the environment blindly selects or shepherds the survivors for which there is room. In engineering terms, the environment is a filter, passing some, rejecting others.

This model of evolution is exceptionally stingy with the number of assumptions. Neither a power nor a direction attaches to evolution, or to life itself. Nothing is synchronized, and no process has a motive. Life experiments with weaker variants as well as stronger types; in fact, weaker variants would be the rule. The geological and atmospheric processed need not work in synchronism with life changes, nor does evolution require a reserve potential, like a coiled spring, ready to expand with a direction when released or triggered.

The model predicts many well-known phenomena. It offers direction for research in its novel predictions. Biologists should look for a unique limiting parameter for each species in steady state. Researchers might create an isolated biome and observe what happens when one species is culled to a very small number. They might repeat the experiment with two competing species.

The environment works through Natural Selection much like a cookie cutter on the dough of life. Evolution is the arrangement of the cookies into the most probable family tree.

Economic Analog

This Theory of Evolution is analogous to an economic mode for a free market economy. Life forms (business ventures follow the opportunistic principal. New species and varieties (businesses and products) will evolve wherever an unsaturated niche (need plus money) exists. During long stable periods, competition diminishes as survival of the fittest (monopolies) take effect. Species (businesses) will become less and less robust, or more and more specialized, during long periods of stability in the environment (market place). Robust means adaptable to unique or extreme environmental (market) conditions.

Environmental (market) variability keeps species (businesses) viable and robust. Dinosaurs (IBMs and GMs) loose robustness to become increasingly vulnerable to minor change. Long term success in a stable environment is a sure warning sign of trouble on the horizon.

The model formulated here should qualify as a theory for evolution, but it is only a conjecture when applied by analogy to the domain of an economy. The notion has a certain intuitive attractiveness, strengthened by the descriptive value of the words used. *Dinosaur* encompasses the idea of over-specialized and cumbersome in everyday speech. Surprisingly, this usage does not appear in popular dictionaries! The word *niche* is common in both business and biology in the both applications of the model.

However, the premises of the Theory of Evolution are far from established in economics, even in an idealized, free-market sense. They would require that business have the inherent ability and tendency to expand without limit, given the demand. Signore Antonio Stradivari ran a successful business in old Cremona, but even with both sons cranking the business could not grow in their output of violins and cellos. If the concept of his business included all the generations of future family members, then the model might have a better chance. In this case, its niche might have to expand from a simple market for stringed instruments to include the whole of the life support system for man.

Competition in business is also quite different from competition in nature. A supermarket chain cannot move into a competitor's neighborhood store the first sunny day in the Spring. Still, the analogy is fun, and the discussion is educational so long as the scientific method is obeyed.

APPENDIX A
THIS APPENDIX IS FALSE

A Hair perhaps divides the False and True;
Yes; and a single Alif[1] were the clue —
  Could you but find it — to the Treasure-house,
And peradventure[2] to The Master too ... .

Omar (F52, L, p. 160)

Hofstadter's provides a delightful and imaginative excursion into self-referencing in his book *Gödel, Escher, Bach: An Eternal Golden Braid* (H89). In his prize winning work, he presents a semi-formal proof of Gödel's Incompleteness Theorem. This is the theorem that staggered the world of mathematics, as described by Kline in *Mathematics The Loss of Certainty* (K80). Hofstadter begins with a precursor to the Gödel statement, presented in a formal language. That precursor statement G(a) translates into,

G(a) = The statement with Gödel number a is not provable.

This statement has Gödel number u, which when inserted into itself, seems to yield

G = G(u) = This statement is not provable.

Interpreted from both inside and outside the formal system of logic, G must be true!

Now there is a bit of trickery in this judgment about the truth of G. Just as Hofstadter and Kalish & Montague (K64) have different versions of proofs, there are different versions of truth. Within any formal system, logicians apply an arbitrary assignment of truth values to statements, and then examine the statements for consistency. This is not necessarily the same truth value system assigned from outside! Even if the truth systems inside and outside had the same number of values and the same names, the mathematician or logician cannot assume them to be the same. In other words, viewed

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[1]The first letter of the Arabic alphabet, but only a thin vertical stroke.

[2]Perhaps or by chance; random.

from within the formal system, G is not true because it can't be derived. Period. Our formal systems can have consistency and validity, but not truth. The model knows no more of the Real World than the characters in a novel know of the Real World:

> For in and out, above, about, below,
> 'Tis nothing but a Magic Shadow-show
>   Play'd in a Box whose Candle is the Sun,
> Round which we Phantom Figures come and go.
>
> Omar (F52, XLVI, p. 54)

Viewed from outside, nothing in the formal system is true by exactly the same criteria just applied to the sentence G.

Now all of this is not to say that nothing in the world of mathematics is true by man's subjective standards. Indeed mathematicians choose axioms to represent their model of the Real World, implicitly assigning them the value TRUE. Then through logic they develop theorems to the limits of their abilities, checking along the way for revelations and inconsistencies. They accept their prizes for the revelations, and revisit the drawing board for the inconsistencies. So while the truth value assigned within the formal system is arbitrary, it is usually a model at its origins of man's conception of truth in the Real World. Mathematicians could build a fully consistent, logical geometry with all axioms out of whack with the Real World. Logicians could build a well-formed, consistent formal system with all false statements by some external criterion, but usually they don't.

Back to the Gödel construction, this writer is puzzled by the permissibility of replacing a free variable with the Gödel number of a statement which contains a specific representation of the same free variable! Like the penny that disappears in the tumbling blocks, the free variable disappears by a change of coordinates. Here's the magic that a word processor can do with this construction:

The statement with Gödel number (a) is not provable.(A1

turns into

> The statement with Gödel number (The statement with Gödel number (The statement with Gödel number (The statement with Gödel number (...) is not provable.) is not provable.) is not provable.) is not provable. (A2)

Proper substitution in logic allows replacement of all occurrences of a free variable or none. How can it be permissible to replace a free variable with an isomorphic representation of a formula including a representation of that same free variable? Doesn't that seem sneaky? It introduces the worst property of induction. The Gödel substitution it seems should continue at once to infinity, an unending nesting of the images like those in barber shop mirrors.

By construction, G ("This sentence is not provable") is Gödel's counterexample to completeness. Since it contains a reference to a free variable, it doesn't seem too surprising that it is unprovable. We might have a theorem that all such instances are unprovable. Personally and with great regrets this writer confesses to not understanding the proof of Gödel's Theorem on Completeness in anything close to its original form, which is in German, or even in any advanced form. Therefore, he cannot state whether this problem is his, Hofstadter's, or Gödel's and the whole world of mathematicians!

If Ramanujan II were to write in his introduction that he intends to question Gödel's Theorem on Completeness, no mathematician would read on. The work would be deemed unworthy of consideration on the face of it. Many others would immediately attack his work as erroneous, amateurish. Such is the strength of the belief, even faith in this now irrefutable theorem. Therefore, it remains unchallenged. Given a Ramanujan II, where would one find a Hardy II?

Are all unprovable instantiations and paradoxes self-referencing? Since Gödel's Theorem is proved, what would happen if a mathematician were to construct a formal system to exclude self-referencing constructs, or to set them aside from other formulas. Here are two alternative suggestions:

Every statement is TRUE or FALSE or SELF-REFERENCING. (A3)

Law of the Excluded Middle - $P \vee \bar{P} \vee P[P]$ (A4)

where P is a statement in the calculus, and P[P] means that P is a member of the class of self-referencing statements. Now, in either new system, the sentence which appeared twice before in the *Evolution of Science* as a paradox,

$$\boxed{\text{THE BOXED SENTENCE IS FALSE.}}$$

is no longer troublesome. By the new rule of logic, it is permissibly self-referential.

APPENDIX B
COMBINING FORMS

-acy	quality
-agra	seizure of pain, illness
-an, -ean, -ian	of, belonging to, skilled in, resembling
-arch	ruler, leader; having points of origin
-ase	enzyme
-ate	act upon, characterized by, office
-cene	recent
-ectomy	cutting out, surgical removal
-er, -ier, -yer	person; one that is, has, or does
-gen, -gene	one that generates, one that is generated
-gram	drawing, writing, record
-graph	written, writing instrument
-ia	division, condition
-ish	of or belonging to, having a trace of
-ism	doctrine, belief system
-ist	follower
-ite	adherent, native, descendent; salt or ester
-ity	quality or state of
-ive	performs, serves to, tends toward
-logy	discourse, study
-ment	result, object, agent, action, process, place
-metros	measure
-odont	tooth
-onym	word
-ophis	snake, serpent
-ornis	bird
-ose	sugar
-ous	full of, abounding
-petal	moving toward
-phyta	of plants
-phyte	plant of specific characteristic or habitat
-pithecus	ape
-poda	having feet

-ptera	feather, wing
-stoma, *-stomum,* *-stomus*	mouth, opening
-stomy	surgery to create an opening
-trophic, *-trophous,* *-trophy*	kind of nutrition
-zoic	animal, animal like; of a geological era
ac-	to, toward, before
acu-	needle
ad-	near, adjacent to
aden-	gland
aer-, aero-	air, gas
albo-	white
allo-	reversal
ambi-	both
ano-	up
ante-	in front of, prior
anti-	opposing
api-	bee
arch-	chief, preeminent, first
archae-, *archaeo-,* *archeo-*	antiquity, ancient, primitive
astro-	star
atmo-	vapor
auri-	ear
aut-, auto-	self
bi-	two
carpo-	seeds
cen-	recent, novel
centi-	hundred
cephal-, cephalo-	head
cera-	horned
chrom-, chromo-	color, pigment

dactyl-, dactylo-	finger, toe, digit
deca-	ten
demi-	half
dent-, denti-, dento-	tooth
dera-	neck
derm-, derma-	skin
di-, dia-	through, during
dipl-, diplo-	double, two
dors-, dorsi-, dorso-	back
duo-	two
dy-, dyo-	two
dyna-	power
dys-	abnormal, diseased, reversed, absence
ec-	household, environment
ect-, ecto-	outside, without
end-, endo-	within, inward
enne-	nine
ent-	inner, within
eo-	dawn, earliest
ep-, eph-, epi-	upon, besides, anterior, prior, after
erg-, ergo-	work, energy
eso-	within
ex-, exo-	out of, away from, without, outside, outer
extra-	outside, beyond
filli-	thread
gen-, geno-	one that generates, one that is generated
geo-	earth
gyne-	female
gyro-	round
hapt-, hapto-	contact, combination
hecto-	hundred
helio-	sun

hemo-	blood
heter-, hetero-	other
hist-, histo-	tissue
hol-, holo-	complete, entire, whole, similar, uniform
ideo-	idea
idio-	individual, peculiar
inter-	among, shared
intra-	within, between, during
ischi-, ischio-	hip
iso-	equal
kino-	moving
lact-, lacti-, lacto-	milk
lith-, litho-	stone
mal-	bad, ill
medi-	middle
mega-	great, powerful
mela-	black
mes-, meso-	in the middle
mille-	thousand
mi-, mio-, meio	less, smaller, fewer, slightly
mono-	one
morph-, morpho-	form, shape, structure
multi-	numerous
nasi-	nose
nema-	thread
neo-	contemporary, new
neuro-	nerve
non-	not
ob-	inward, incomplete, in reverse order, inverse
oct-	eight
oculo-	eye
oleo-	oil

olig-, oligo-	few, deficiency, little
omni-	all
omo-	shoulder
oo-	egg
ophi-, ophio-	snake, serpent
ori-	boundary
ornith-, ornitho-	bird
oro-	mountain
orth-, ortho-	straight, upright, correct
oste-, osteo-	bone
oto-	ear
ovi-	egg
pale-, paleo-	remote, ancient, early
pan-, pano-	all
pari-	equal
ped-, pedi-, pedo-	foot
penta-	five
per-	throughout, through
phot-, photo-	light
physi-, physio-	nature, natural, physical
phyt-, phyto-	of plants
pil-, pili-, pilo-	hair
pleio-, pleo-, plio-	more
pleisto-	most
poly-	many
post-	after, subsequent, later, posterior
pre-	in advance, before
pri-	saw
pro-	siding with, favoring
proter-, protero-	before, earlier, former
pseud-, pseudo-	false, deceptive, abnormal
pter-, ptero-	feather, wing

quadr-, quadri-, quadru-	four, square, fourth
semi-	half
sero-	thin, watery
sito-	food
soma-	body
steno-	narrow, small
stom-, stomo-	mouth
sur-	above, beyond
tac-	touch
tel-	far
tent-	ribbon
ter-	three
tetra-	four
ther-, thero-, -therium	wild beast, animal
therm-, thermo-	heat
toto-	whole
tri-	three
un-	not
uni-	numerical
vari-	various
vermi-	worm
xeno-	strange
xer-, xero-	dry
xylo-	wood

APPENDIX C
BIOLOGY MATHEMATICS

To teach biology without mathematics is to teach half a subject. Mathematical models are translations of prose models, stat ements in natural language, that strip the language of its ambiguity while extending it to its full range of implications. The time has long since come to bring mathematical modeling to the forefront in biology training. Modern texts and the California Science Framework choose instead to obscure, misrepresent and down play the role of mathematics.

Consider, for example, the following from *Biology*, a college level introductory text. A chart entitled "Selection against a lethal allele" shows experimental data and a curve. The author shows the information plotted rectangularly, where the abscissa is "Generation" from 0 to 12 and the ordinate is "Frequency of lethal recessive" and ranges from 0 to 0.5. The curve is a simple declining hyperbola with a dozen data points. The caption says,

> The points on this graph track the generation-by-generation decline of a lethal recessive allele in a laboratory population ... . At the beginning of the experiment, the recessive lethal and the dominant allele were present ... in equal frequencies ... . The relative fitness of the homozygous dominant genotype is 1, and the fitness of the heterozygous genotype is only slightly less (but not quite 1, because the 'normal' allele for this locus is not completely dominant to the lethal recessive). The homozygous recessive genotype has a relative fitness of 0; death results before any offspring are left. Put another way, the homozygous recessive genotype has a selection coefficient of 1 ... . The curve represents the expected decline in the frequency of the lethal allele based on selection theory, and the actual data ... fits the expected results closely. Note that the rate at which the lethal allele disappears from the population slows as the allele becomes less common. This is because a greater proportion of remaining recessive alleles are present in heterozygotes compared to homozygotes as the allele becomes rarer. (C90, Fig. 21.11, p. 452)

The mathematical formula for the curve in that figure is given nowhere — not in the text, not in the caption, and not on the chart. A little effort well within the scope of high school algebra will show that the equation is

$$f_n = \frac{1}{n+2} \tag{C-1}$$

Why? Where does this equation come from? What are the assumptions that support it? How closely do the data fit? Why is there any disparity between the data and the curve at all? The caption references the fact that the fitness of the heterozygous genotype is slightly less than one. How much less, and is that reflected in the model?

The equation above should be derivable by high school students, and that ability might serve as one measure of student training. The technique involved is rich in mathematical and biological content. Well-prepared high school students should find several special and important solutions in closed form, and they should be able to model any solution on their personal computers for numerical and graphical study. *Evolution in Science* solves it here for the pedagogical value. Many such examples can be found in other fields of science.

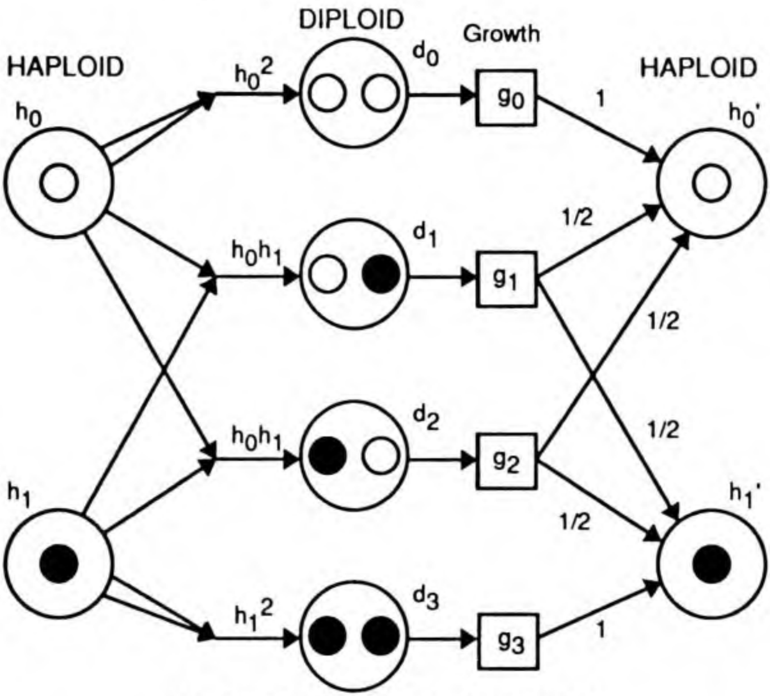
POINT 1: PROBLEM IDENTIFICATION

When a variant occurs spontaneously in nature, we want to know what we can of the evolutionary process. What are the conditions for one variety to replace another. Are there conditions under which both can coexist in steady state?

The problem is to find how the ratios of genotypes and phenotypes vary in a population, for they are measures of the evolutionary process. The modeling begins with the representation of a single pair of alleles found abundantly within a population. We ask how the distribution of the two will change in time, depending on the number of offspring, the survival rate, and whether the allele is dominant, recessive, or something in between.

POINT 2: STATE DIAGRAM

Prepare a *state diagram* of the problem statement. This rather standard drawing in this biology problem expresses the transitions from a single pair of alleles:



ALLELE PROPAGATION

Figure C-1

The large circles called bubbles stand for *states* in which objects can logically reside, and the squares represent *operations*, in this instance multiplications. The arrows are *transitions* between the states and through the operations. The numbers represent *probabilities* or *densities*. High school students should practice this art.

Population problems are particularly challenging because they are non-linear! The model postulates a genetic pool for two alleles, shown in the Haploid state on the left. The numbers h_0 and h_1 are the relative densities or probabilities of each, and must total one. All possible pairings are shown, assuming that they form equally likely[1]. The probabilities of each diploid type are shown as $d_0 = h_0^2$, $d_1 = d_2 = h_0 h_1$, and $d_3 = h_1^2$, which is the Cause of the non-linear Effect. The model retains a certain symmetry and generality if one keeps two heterozygote forms, but we will set $g_1 = g_2$ at the earliest convenience. We will refer to these two heterozygote forms as different genders.

Following each diploid pair is a growth factor, g_i. In this model, the growth factor represents the product of the probability of survival for the genotype and the number of offspring produced in a generation per individual. It represents a net number of offspring, assuming the parents do not reproduce again.[2] Each genotype is assumed to produce each gamete type with equal probability of 1/2.

The problem is to calculate the probabilities h_0' and h_1'. The student can program a numerical solution from this diagram using standard spread sheet application programs. However, a superior pedagogy is for the student to exhaust analytical techniques first. The analytical method provides much more insight as well as direct parametric relationships and

---

[1]Equally likely pairings is another assumption for research and analysis. It should be examined using the Scientific Method. However, it is not an Achilles' heel in the population model in any sense. The student should flag the assumption for later testing. He should be sure that his model keeps that assumption accessible for experimentation. After he has achieved results with the assumption, he can return to it. By varying the distribution of pairings, he can provide a valuable sensitivity analysis for his model.

[2]If the parents always survive to reproduce again, the factor is half the number of offspring per pair plus one. A more sophisticated analysis might account for a finite number of reproduction cycles per parent.

cross-checks against mere computer-generated numbers. Except in space and some high risk military applications, the state-of-the-art in computer programming does not include independent algorithms to check one another either for precision or for order of magnitude.

POINT 3: EQUATIONS IMPLIED BY THE DIAGRAM

The standard analytical technique is to solve first for the recursive relationship between the pair $\{h_0,h_1\}$, which can also be written as $\{h_0(n),h_1(n)\}$, and the output pair $\{h_0', h_1'\}$. Next we find the general expression for the output at the n^{th} generation, designated $\{h_0(n+1), h_1(n+1)\}$, and its dependence on the initial conditions. These equations follow easily from the state diagram.

$$h_0' = \frac{g_0d_0 + \frac{1}{2}g_1d_1 + \frac{1}{2}g_2d_2}{\Sigma}$$

$$= \frac{g_0h_0^2 + \frac{1}{2}(g_1+g_2)h_0h_1}{\Sigma} \qquad \text{(C-2)}$$

$$h_1' = \frac{\frac{1}{2}g_1d_1 + \frac{1}{2}g_2d_2 + g_3d_3}{\Sigma}$$

$$= \frac{\frac{1}{2}(g_1+g_2)h_0h_1 + g_3h_1^2}{\Sigma} \qquad \text{(C-3)}$$

where Σ, standing for sum, is the normalizing factor,

$$\Sigma = d_0g_0 + d_1g_1 + d_2g_2 + d_2g_2$$

which we won't need to calculate. Instead, we use the fact that h_0 and h_1 are mutually exclusive and exhaustive probabilities, implying that

$$h_0(n) + h_1(n) = 1. \qquad \text{(C-4)}$$

POINT 4: INTRODUCING THE RATIO PARAMETER

If the student finds himself stalled at this point, provide the following hint. Introduce the ratio

$$r' \triangleq r(n+1) \triangleq \frac{h_0(n+1)}{h_1(n+1)} \qquad \text{(C-5)}$$

$$= \frac{g_0 h_0^2 + \frac{1}{2}(g_1+g_2)h_0 h_1}{\frac{1}{2}(g_1+g_2)h_0 h_1 + g_3 h_1^2}$$

Dividing the numerator and denominator by h_1^2 yields,

$$\boxed{r' = \frac{g_0 r^2 + \frac{1}{2}(g_1+g_2)r}{\frac{1}{2}(g_1+g_2)r + g_3}} \qquad \text{(C-6)}$$

Equations C-4 and C-5 yield

$$r(n) = \frac{1}{h_1(n)} - 1$$

so

$$\boxed{h_1(n) = \frac{1}{r(n) + 1}} \qquad \text{(C-7)}$$

So if we solve for r(n) using C-6, we will have $h_1(n)$ rather easily.

POINT 5: SIMPLIFYING THE PROBLEM

So far, the equations expressed all possible parameters. This method retains symmetry, making the equations easier to write and debug. This also assists in their solution on computers. To continue the analysis, however, the promised simplifications are now in order.

Since we are dealing with ratios and proportions in the population, we can set $g_0 = 1$ without loss of generality. Furthermore, the statement of the problem does not require either gender dependent survival or reproduction rates, so set $g_1 = g_2 \triangleq g_D$. The symbol g_D indicates that this heterozygote growth factor will refer to the dominant allele. Similarly, set $g_3 = g_R$ to represent the recessive state for the homozygote. Now C-6 becomes

$$\boxed{r' = \frac{r^2 + g_D r}{g_D r + g_R}} \tag{C-8}$$

POINT 5: INITIAL CONDITIONS

The relations for r(n) expressed by either C-6 or C-8 are recursive, meaning that the value of r depends on its previous value. Solving recursive relations requires a starting point, called *initial conditions*. As a start, set the following conditions:

Initial Conditions 1:

$$h_0(0) = h_1(0) = \frac{1}{2}$$

so

$$r(0) = 1 \tag{C-9}$$

POINT 6: TRACTABLE CONDITIONS

What conditions make the analytical solution tractable? The form of the recursive equation, C-8, suggests two possibilities. Condition I is the lethal recessive condition desired by the problem statement:

$$g_3 = g_R = 0 \tag{C-10}$$

The second Condition II is due solely to the form of C-8. It makes the denominator a factor of the numerator.

$$g_R = g_D^2 \tag{C-11}$$

This condition does not imply a functional relationship between the recessive and dominant growth rates. The relationship is useful if it represents a simple empirical coincidence, as for example if $g_D = 1.1$ and $g_R = 1.21$.[3]

Each of Condition I and II reduces the problem to a single growth parameter, so for ease of notation, let

$$g_D = g. \tag{C-12}$$

POINT 7: CONDITION I: LETHAL RECESSIVE

The ratio, r, in C-8 becomes

$$r' = rg^{-1} + 1 \tag{C-13}$$

The solution to this is

$$r(n) = r(0)g^{-n} + \sum_{k=0}^{n-1} g^{-k} \tag{C-14}$$

The density of the recessive allele is

$$h_1(n) = \frac{1}{r(0)g^{-n} + \sum_{k=0}^{n-1} g^{-k} + 1}$$

---

[3]This difference between a functional relationship and a point relationship needs emphasis. It is analogous to the following. If a mother is twice as tall as her daughter, that is an observation at a particular time. It is not a relationship between the heights of the two that holds at all times.

$$h_1(n) = \frac{1}{g^{-n}h_1^{-1}(0) + \sum_{k=0}^{n-1} g^{-k} + 1 - g^{-n}} \qquad \text{(C-15)}$$

When the dominant growth rate, g, is one, we have

$$h_1(n) = \frac{1}{h_1^{-1}(0) + n},\ g = 1 \qquad \text{(C-16)}$$

Otherwise, the high school student uses a simple relation for the sum to find

$$h_1(n) = \frac{1}{g^{-n}h_1^{-1}(0) + (1-g^{-n})(2g-1)/(g-1)},\ g \neq 1 \qquad \text{(C-17)}$$

Formally, these expressions are usually combined as follows as a complete solution:

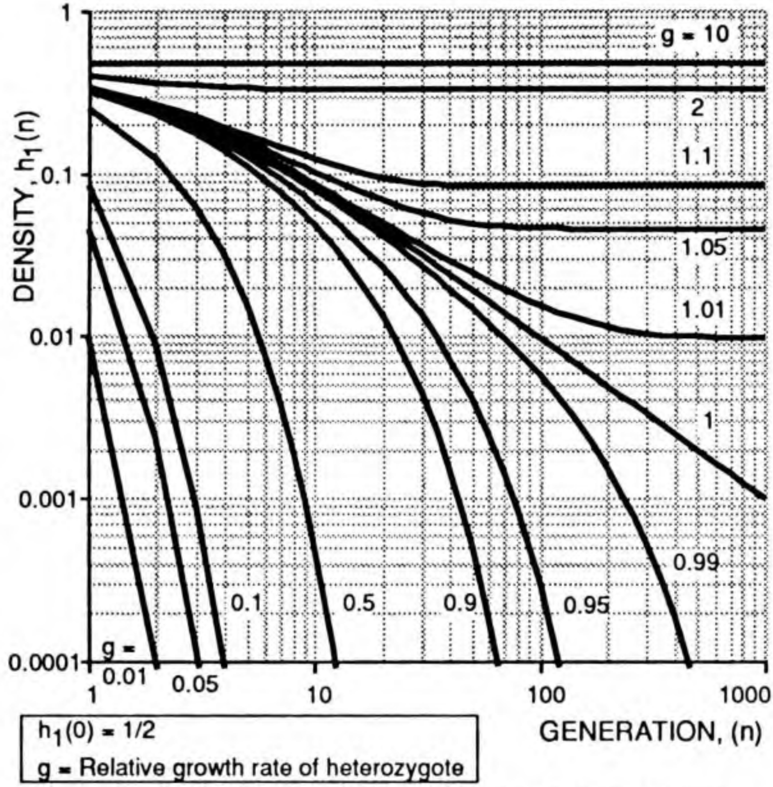
$$\boxed{h_1(n) = \begin{cases} \dfrac{1}{h_1^{-1}(0)+n},\ g = 1 \\[2ex] \dfrac{1}{g^{-n}h_1^{-1}(0)+(1-g^{-n})(2g-1)/(g-1)},\ g \neq 1 \end{cases}} \qquad \text{(C-18)}$$

POINT 8: LETHAL RECESSIVE GRAPH

The behavior of the population of lethal recessive alleles is best visualized on a logarithmic graph, as shown below for

$h_1 = \frac{1}{2}.$

Varying the parameter g produces a graceful family of curves about the line for g = 1, shown on the next page. The sharp decline in the populations for g < 1 and the retention of a non-zero population for g > 1 are subjects of further analysis. Students should prepare the graph in both linear and logarithmic form, along with asymptotes derived below.



LETHAL RECESSIVE ALLELE DENSITY

Figure C-2

POINT 9: SENSITIVITY TO INITIAL CONDITIONS

Retaining the initial condition $h_1(0)$ explicitly in the final expressions teaches the student how initial conditions decay in these well-behaved formulae for the density of the allele. Once numerical values replace the initial condition parameters, that dependence is lost. For example, under Initial Conditions 1, we have from C-16

$$h_1(0) \qquad \text{(C-19)}$$

This is the formula graphed in *Biology*, Figure 21.11 Selection against lethal allele." The importance of the initial condition is lost in the text. If the initial density $h_1(0)$ were $\frac{1}{3}$, for example, then we would have

$$h_1(n) = \frac{1}{3+n}, \qquad \text{(C-20)}$$

causing the curve to shift to the left one generation! At this point, the student has a hint of the effects of the initial condition and the asymptotic behavior of the evolutionary process. A small, additive shift in the abscissa isn't going to have any appreciable effect for large n.

POINT 10: EXPLORING BEST FIT TO DATA

Having discovered that the text used equation C-19 shows that the author did not compute the curve for g "slightly less than one", which is available from C-17! That computation should have been made and the value to g optimized for fit with the data using elementary mathematical and scientific techniques. That might have important biological implications. It would provide a measure of closure between the verbal model and the math model through empirical data. This validation process strengthens both biological models by improving their accuracy.

POINT 11: ASYMPTOTIC BEHAVIOR

The original problem is one of learning how a recessive allele decays from the population, not the precise density starting from a known initial condition. To understand this better, the high school student should let n approach infinity in equation C-18. The technique is not to find the limit, but rather the algebraic dependence as n becomes so large as to swamp mere additive constants. This is called the *asymptotic behavior*.

When the dominant growth factor is one, the density is easily seen to be

$$h_1(n) \underset{n \to \infty}{\to} \frac{1}{n}, \quad g = 1 \qquad \text{(C-21)}$$

This is a hyperbolic decay, and is quite slow.

When g is less than one, we need to rewrite C-17 to portray better the behavior for large n:

$$h_1(n) = \frac{g^n * h_1(0)}{1 + (g^n - 1)((1-2g)/(1-g))h_1(0)}, \quad g < 1 \qquad \text{(C-22)}$$

which yields

$$h_1(n) \underset{n\to\infty}{\rightarrow} g^n * \frac{1}{h_1^{-1}(0) + 1}, \quad g < 1 \qquad \text{(C-23)}$$

So the initial condition decays approximately exponentially. that is by the power of g^n. The asymptote is scaled upward by the amount of the denominator in C-23. This is equivalent to a shift to the right of the curve as compared to a straight forward decay of $h_1(0)$.

A surprising situation arises when the allele is dominant in the heterozygote. Here, the growth, g, is greater than one, and the limiting behavior from C-17 is

$$h_1(n) \underset{n\to\infty}{\rightarrow} \frac{g-1}{2g-1} < \frac{1}{2} \qquad \text{(C-24)}$$

This shows that in steady state neither allele vanishes! Front C-4, the density of the other allele approaches

$$h_0(n) \underset{n\to\infty}{\rightarrow} \frac{g}{2g-1} > \frac{1}{2} \qquad \text{(C-25)}$$

Under Condition I, the complete limiting behavior becomes

$$h_1(n) \underset{n \to \infty}{\rightarrow} \begin{cases} g^n * \dfrac{1}{h_1^{-1}(0) + 1} & , g < 1 \\ \dfrac{1}{h_1^{-1}(0) + n} & , g = 1 \\ \dfrac{g - 1}{2g - 1} & , g > 1 \end{cases} \qquad \text{(C-26)}$$

Returning to plain English, the conditions on the growth vector have the following meanings.

Growth Factor, g	Recessive Homozygote	Heterozygote
< 1	Lethal	Less prolific than homozygote
1	Lethal	As prolific as homozygote
> 1	Lethal	More prolific than homozygote

And referring back to the state diagram, what happens to the density of the lethal recessive homozygote?

$$d_3(n) \underset{n \to \infty}{\rightarrow} \begin{cases} \left(g^n * \dfrac{1}{h_1^{-1}(0) + 1}\right)^2 & , g < 1 \\ \left(\dfrac{1}{h_1^{-1}(0) + n}\right)^2 & , g = 1 \\ \left(\dfrac{g - 1}{2g - 1}\right)^2 & , g > 1 \end{cases} \qquad \text{(C-27)}$$

where $g_D = g$ and $g_R = 0$. When the heterozygote is less prolific than the surviving homozygote, the doomed homozygote vanishes exponentially; and when the meterozygote is as prolific, the doomed variety vanishes more slowly, specifically as $\frac{1}{n^2}$. Where the probability decays hyperbolically, the density being proportional to the square of the probability decays quadratically[4]. Otherwise the heterozygote is more robust than either homozygote form, and the completely unproductive homozygote form, a drone, achieves equilibrium in the population, for it is created as fast as it dies.

POINT 12: SOLVING CONDITION II

Recall from C-11 and C-12 that

$$g_R = g_D^2 = g^2$$

so that the ratio, r, is now

$$r' = \frac{r^2 + gr}{gr + g^2} = rg^{-1} \qquad \text{(C-28)}$$

The solution of this equation is

$$r = r(0)\, g^{-n} \qquad \text{(C-29)}$$

The density of the recessive allele is now

$$h_1(n) = \frac{1}{r(0)\, g^{-n} + 1}$$

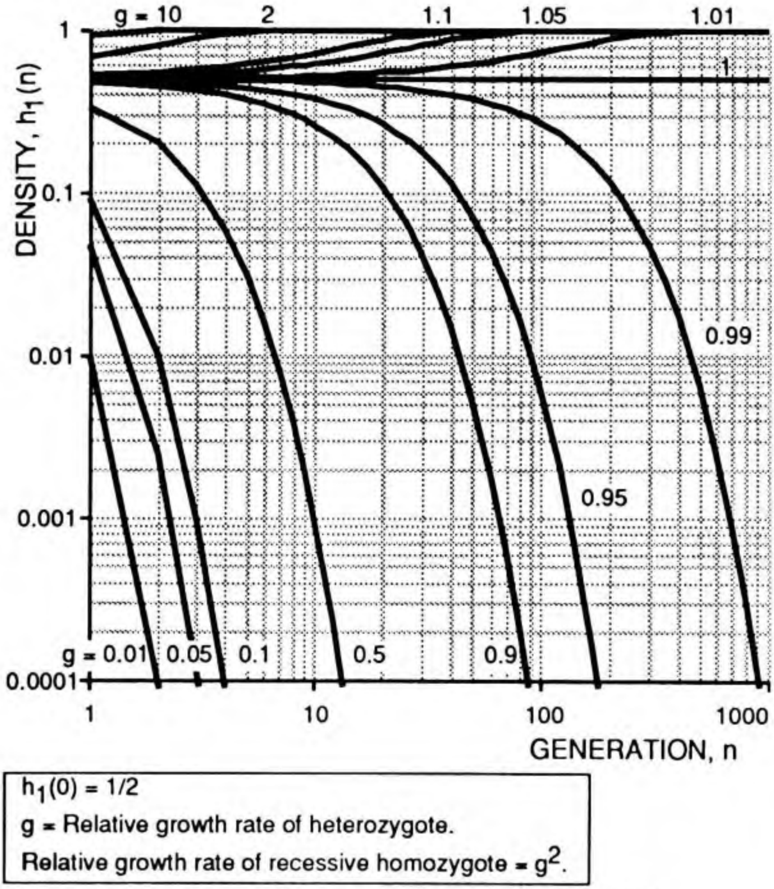
$$\boxed{h_1(n) = \frac{1}{g^{-n} h_1^{-1}(0) + 1 - g^{-n}}} \qquad \text{(C-30)}$$

---

[4]For consistency, a better name would be parabolically. The convention is to call $\frac{1}{n^2}$ quadratic, and $\frac{1}{n}$ as simply "one over n".

POINT 13: GRAPHING CONDITION II

The graph of the allele density under Condition II appears below. It also has a symmetry about the line for g = 1, which is now horizontal.



RECESSIVE ALLELE DENSITY

Figure C-3

If g = 1, $h_1(n)$ is constant; that is, $h_1(n) = h_1(0)$. If g > 1,

$$h_1(n) \underset{n\to\infty}{\rightarrow} 1 \tag{C-31}$$

and the allele previous dominant by default now vanishes in time.

If $g < 1$, equation C-26 yields

$$h_1(n) \underset{n\to\infty}{\to} g^n \frac{h_1(0)}{1 - h_1(0)}\ , \ g < 1 \qquad \text{(C-32)}$$

as when the recessive heterozygote was lethal.

Under Condition II, the complete limiting behavior can be written as

$$\boxed{h_1(n) \begin{cases} \underset{n\to\infty}{\to} g^n \dfrac{h_1(0)}{1-h_1(0)} & , g < 1 \text{ (less prolific)} \\ = h_1(0) & , g = 1 \text{ (equal)} \\ \underset{n\to\infty}{\to} 1 & , g > 1 \text{ (more prolific)} \end{cases}} \qquad \text{(C-33)}$$

and

$$\boxed{d_3(n) \begin{cases} \underset{n\to\infty}{\to} \left(g^n \dfrac{h_1(0)}{1-h_1(0)}\right)^2 & , g < 1 \text{ (less prolific)} \\ = h_1^2(0) = d_3(0) & , g = 1 \text{ (equal)} \\ \underset{n\to\infty}{\to} 1 & , g > 1 \text{ (more prolific)} \end{cases}} \qquad \text{(C-34)}$$

where $g_D = g$ and $g_R = g^2$. In this interesting solution, recessiveness and dominance become ambiguous. The prolificness of the form depends on the product of the prolificness of each allele. The more prolific forms will completely replace the lesser forms, where the latter decline at exponential rates. If the two forms are equal in reproductive power, no population changes take place.

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INDEX