PREFACE

Earth is unique, a planet of rare beauty and great value.

I firmly believe that conclusions about global warming reached by researchers, such as those at my university in the Byrd Polar Research Center, are valid and based on very solid science. They are telling us that humans, by their actions, are causing the global climate to change. It therefore puzzles me when politicians, representatives of the business community, and even some physicists and chemists, make public statements that this is "junk" science. Or that it is just another "chicken little" scare of the "environmentalists". Studies on public understanding of science among Americans by Jon Miller and his colleagues and the current political power of those advocating "creation science" as a component of the science curriculum, suggests to me that there is a deep misunderstanding of the nature of science here in the United States, perhaps shared by some.scientists If the resources devoted to the improvement of science teaching and curriculum following World War II had been effectively used I would expect that there would be an acceptance of good science by influential members of our society, and by most citizens. However, I do believe that the programs supported by the National Science Foundation over the past forty years have been effective in establishing strong science programs in our schools. After all, my colleagues and I have been recipients of some of that support for curriculum and teacher enhancement programs.

My hypothesis concerning this apparent paradox is that these science teaching renewal programs have given priority to the perceived needs of a country in conflict. As a result, they focused on the type of science supporting our technical needs, neglecting an equally important part of science, what we in this book are calling the "system sciences". Such neglect has continued throughout the science restructuring programs taking place in the USA and elsewhere around the world--thus, the need for this book.

The need to re-examine our goals for science curricula

We have just ended a long period of conflict between the major nations, the Cold War. Science and science education played a central role in waging that war and the "hot wars" that preceded it. Now, however, science education and its practitioners have the opportunity of supporting changes in the goals of science as it adjusts to a new era. Science is being challenged by some to provide the knowledge to counter the devastating environmental problems that have been by-products of a century of war and economic conflict. It also can be employed to help solve the social problems resulting from the unfettered use of technology for political and economic gain. To support science in redirecting its goals, science educators must re-examine the very nature of science and its role in social, cultural and political systems. We must understand the broad nature of science and its methodologies, an understanding not always apparent in the professional dialog of science educators. It is our belief that such a re-examination will result in a significant change in science education; a change founded on the view that science is, after all, a study of the Earth System in which we all live, not simply the basis for the pursuit of ever more technology.

This book offers a rationale and a developmental basis for such a re-examination. Authors from six countries, representing East and West, provide support and ideas for application of a different approach to the nature of the science curriculum. One we have called, Global Science Literacy. Most authors come from an Earth science academic background, but there also are physicists, chemists, and biologists represented as authors or co-authors of chapters. Global Science Literacy (GSL) is based on developments in the United States that resulted in an approach called Earth Systems Education (ESE), a curricular basis for literacy in science.

Earth Systems Education (ESE) uses the Earth system as the organizing conceptual theme for developing science curricula for the middle through high school levels. Children of all nations experience weather, flowing streams, and rock materials as parts of their environment. They observe the beauty of sunsets, the power of storms, the tranquility of a mountain scene, a flowing river, or an autumn day. A science curriculum organized around students' interdependence with nature and tapping into their interests in nature provides a common subject for study in all cultures. ESE includes the science methodology of the system sciences, a distinct contrast from the prevailing emphasis upon that of the physical sciences in the world's science curricula. A facility with the use of science methodology can provide the world's future citizens with universal methods of communication and problem solving as they enter the adult world.

This book is, in part, the result of an international process of expanding ESE into a Global Science Literacy program that includes a cooperative effort between faculties of The Ohio State University and Hyogo University of Teacher Education (Japan). A seven-month long global education project at Hyogo University provided an opportunity to synthesize many ideas that had evolved over the years of involvement by the authors in Earth science education. We have formulated a global version of science literacy for pre-college education that will not only improve citizens' understanding of science, but also enhance cross-cultural communication and understanding. We have also examined selected Asian cultures and drawn implications for a science program more in concert with those cultures, especially with its incorporation of system science methodology. In addition, a Fulbright grant for a subsequent project allowed us to evaluate Global Science Literacy as a basis for curriculum development at the upper secondary school level in Japan. This project was located at Shizuoka University and in the Division of Educational Research of Monbusho. Through contacts made during international conferences and professional trips, science educators from thirteen countries have become involved in enhancing and expanding ideas relating to Global Science Literacy.

The resulting matrix of science and social concepts and processes are proposed as a functional international definition of science literacy. If implemented in school curricula of democratic nations, we believe it will help citizens understand the role of science in solving environmental and social problems left in the wake of a century of world war and economic conflict. It can also contribute to cross-cultural understanding and cooperation between citizens and leaders of the democracies of the world. Thus, science curricula can have a crucial role among other curricular subjects in helping students achieve a global understanding and perspective--a major objective of the social studies curriculum construct of global education.

Organization of the book

In the first section of the book, we lay the historical, conceptual and philosophical groundwork for GSL, a science curriculum, international in scope, conceptual in organization, centered on the students and their habitats and representative of the very broad methodology used by scientists. In the second section, authors discuss a variety of learning environments, which, though not new to GSL, are supportive of the basic goals of the curriculum effort. These environments include the Internet, cooperative learning, effective reading materials, field investigations, and authentic assessment. In the third and last section, certain issues in curriculum development are discussed with a GSL perspective. How does one develop curriculum that is conceptually organized rather than organized by the traditional disciplines? How can GSL curricula be adapted for special learners? How can field activities and aesthetics be integrated in GSL curricula? The final chapter reports the research study conducted in Japan that looked at the feasibility of implementing GSL curricula at the upper secondary school level in that country.

Personal reflections

One of the best practitioners of "applied science" I knew was my father. I grew up on a farm in Wisconsin. My father went no further than eighth grade in his formal schooling. From when he was a child until he retired, he worked almost every day milking cows, planting and harvesting hay and grains, and the various other duties that went into being a successful farmer. Helping him as a child, I did not understand why he did certain things. In the spring, he would plow fields following the contours of the land instead of up and down hills even though that would often have been much easier. He also alternated different crops in parallel strips around the hills. In successive years, he would alternate crops within a single strip. He allowed trees and brush to grow along fencerows harboring animals and birds that often fed off the crops he was raising. Although he kept a bull on the farm for breeding the cows, after I became a teen-ager he sold it and joined an artificial breeding cooperative. He soon became a member of its board of directors, responsible for choosing good breeding stock, recommending technical procedures, etc., all of which took some knowledge of science. Where did he learn the knowledge that supported these practices? Partly from experience and concern. However, he also consulted with our local extension agent, and although I seldom saw him reading (he was usually too busy). In later years, after I moved to Ohio, I learned that he knew about Louis Bromfield. He had read his books, especially those that discussed Bromfield's theories of conservation farming developed on his farm not far from my home in Columbus.

If my father, with a minimum of formal education, could become an applied scientist and conservationist, why not our politicians, lawyers, business people, common everyday citizens? Those schooled in what is generally considered the best university system in the world? I suspect with the proper education in science, such as effective global science literacy programs, they could become well informed in science and of the knowledge science develops concerning our habitat. Education has become the substitute for the kinds of practical experiences formerly shared by my father and his sons. Thus, science education has a fundamental role in providing the experiences and knowledge that will lead to an effective understanding of the Earth system we all share, and that our descendants will inherit. However, it must be the right type of science education. We hope that this book and its focus on Global Science Literacy can be a contribution toward providing the "right" science education.

Acknowledgements

This project started with a discussion on Global Science Literacy with Barbara Klemm in a hotel lounge on the beach at Waikiki, Hawaii. She suggested that we put together a book that would spell out the basis and philosophy of the concept. I am thankful for her idea and the constant interest and encouragement she has provided during this project. I also appreciate the enthusiasm expressed by each of the authors and the quality of their composing and writing efforts. Almost all of our communications were accomplished over the Internet via a GSL homepage and email. The authors' responses to editing requests, and suggestions for modifications were always prompt and accurate.

A modest amount of funding was available for the actual production of the manuscript and a presentation on the book at a conference of the National Association for Research in Science Teaching. The funds came from the Alphyl Memorial Fund at The Ohio State University. This is a fund established by students and colleagues to support activities in Earth Systems Education. It is named in honor of Victor and Phyllis Mayer, my parents. Alphyl is a combination of the first letters of my mother's and her mother's first names. It is the name of the farm in Wisconsin worked by my father and the birthplace and early home of his three sons.

VJM
Columbus, Ohio, USA
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CHAPTER 1: EVOLUTION OF GLOBAL SCIENCE LITERACY AS A CURRICULUM CONSTRUCT

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1. INTRODUCTION

Science as a major component of school curricula can provide a model of a process for effective communication and decision making across barriers to understanding imposed by differences in culture and language, a fundamental objective of the social studies curriculum construct of global education (Anderson, 1992). The scientific process can provide a model for achieving dialogue among peoples with different languages and from diverse cultures. Science in school curricula can also become a common meeting ground for science teachers and social studies teachers. It provides an avenue of linkage between the curricular areas and an opportunity for interdisciplinary planning and teaching. Together social studies and science teachers can help to ensure that our future leaders and voters will understand our interrelationships with peoples around the world and how our daily activities affect our planet and its resources. This is a fundamental goal of global education. It also lies at the core of Earth Systems Education, discussed in the next section of this chapter, and our efforts to develop a global science literacy rationale and program, the topic of this chapter.

Scientists throughout the world have a single shared subject—Earth and its environment in space--and a common method of study and communication--the procedures and language of science. Scientists start with an accurate description of their observations about Earth processes and materials and then go on to develop logical arguments and interpretations based on those observations of nature. But also, science is a collective endeavor. Examine, for example, the authorship credits for a recent research article in one of the premier American scientific journals, *Science*, published by the American Association for the Advancement of Science. It is likely that the article will have several authors from different countries or at least from different cultural heritages. In addition, it will cite the work of many others in the same or related fields of science again often from different countries or cultural heritages. These individuals use the mental processes of science and its language to communicate across their disparate cultural experiences and identities in solving problems or studying processes occurring in our Earth systems.

V.J. Mayer (ed.), Global Science Literacy, 3–24.

Often a science report will challenge the previous work of those cited. Such a challenge is what keeps science honest even though some of its participants may not be. A scientist's work is replicated, or at least reevaluated, by others and is therefore subject to change and reinterpretation or even outright rejection by the scientific community. As individuals, scientists possess all of the frailties of humans. They make mistakes. They might even misrepresent their data. But if so--they will be found out and corrective action taken. The result of these procedures of science, therefore, is a representation of an Earth process or material that has a high probability of representing that aspect of the real world. Scientists throughout the world, always check their work against the same standard, the observations they make of Earth and its environment in space. Thus, science and its subject--the Earth system--provide an international avenue for communication across the barriers imposed by language and culture. As such the methods of science provide a model of a process for the honest evaluation of social issues and decisions on governmental policies and potential actions that can be less susceptible to bias than are other forms of decision making. It provides a model for an individual's evaluation of information received from a variety of sources and a mechanism for making informed decisions in this ever more complex world.

2. DEVELOPMENT OF EARTH SYSTEMS EDUCATION AS THE SCIENCE FOUNDATION OF GSL

In the past twenty years there have been tremendous advances in the understanding of planet Earth from the application of advanced technology in data gathering by satellites and data processing by supercomputers. As a result, Earth scientists have reinterpreted the relationships between the various subdisciplines and their mode of inquiry. These changes are documented in the "Bretherton Report," developed by a committee of scientists representing various American government agencies with Earth science research mandates. The committee was chaired by Francis Bretherton, a meteorologist at the University of Wisconsin (Earth System Sciences Committee, 1988). This reconceptualization of the process and goals for study of planet Earth was called 'Earth System Science'.

We believe that this report establishes a basis from within the science establishment for conceptually organizing science curricula. Earth system science has now become a model for much of the geoscience research carried on in the USA, not only by government agencies, but by academic institutions and industry as well. Earth system science, instead of the discipline oriented approach to the study of the atmosphere, biosphere, hydrosphere, lithosphere, the solar system and the universe, takes an interdisciplinary or conceptual approach. Physicists, chemists, biologists, geologists--scientists from many different disciplines including the social sciences--work cooperatively applying their special knowledge, skills, and methodology to understand how each of the Earth systems work, how they interact, and how humans affect those systems.

Earth processes (taken to include those operating within the Earth system, the solar system and the universe at large) to be the subject of current and future research were divided by the committee into two time scales. One deals with relatively short term processes such as those of weather, climate change, and nutrient cycles. These are the processes potentially influenced by human behavior and occur in relatively short time frames from seconds to hundreds of years. The other time scale includes long term processes, such as plate tectonics and the evolution of life operating over thousands to millions of years. The short-term processes are of special concern to the world community because of the disturbances introduced into the Earth systems over the past century by the invention and application of many technologies and by the rapidly growing world population. An understanding of the long-term processes provides a philosophical place for the human presence within the Earth system. Such a background would assist students to more easily comprehend those essential contributions of Copernicus, Galileo, Hutton, Darwin and others that describe our place in the universe.

The committee defined Earth system science with seven statements (ESSC, 1988, p. 21). The first two contrast the traditional Earth science view with that of the new Earth systems science view.

- The two traditional motivations for Earth science are an understanding of the Earth as a planet and the search for practical benefits from such research.
- Earth system science treats the Earth as an integrated system of interacting components, whose study must transcend disciplinary boundaries.

The third points out the reason for this changing focus of the sciences.

- Earth system science has been stimulated by the maturation of the traditional disciplines, a global view of the Earth from space, and the increasing role of human activity in global change.

The next two points explain the two divisions of processes the committee defined.

- On time scales of thousands to millions of years, Earth processes are driven both by internal energy and the external energy of solar radiation.
- On time scales of decades to centuries, Earth processes are dominated by the physical climate system and the biogeochemical cycles, with human activities playing an increasing role in both.

The goal of Earth system science is:

- .... to obtain a scientific understanding of the entire Earth system on a global scale by describing how its component parts and their interactions have evolved, how they function, and how they may be expected to continue to evolve on all time scales.

The committee sees the challenge of research to be to:

- .... develop the capability to predict those changes that will occur in the next decade to century, both naturally and in response to human activity.

Except for the last point, these statements could be taken to define the nature of a secondary school science curriculum, not just the Earth science curriculum often offered in the ninth grade of American schools.

A second report, dealing only with the solid Earth sciences makes the following recommendation:

> **Efforts need to be made to expand Earth science education to all.** Citizens need to understand the Earth system to make responsible decisions about use of its resources, avoidance of natural hazards, and maintenance of the Earth as a habitat. School systems must respond to this need.... (National Research Council, 1993, p. 12)

This report links the need for better understanding among our citizens to the important needs of society in this post-cold war era. As such it provides important support for readdressing the importance of including significant content about the Earth system in the nations's science curricula.

3. EARTH SYSTEMS EDUCATION

Earth system science can provide science educators with a conceptual approach to curriculum integration as suggested by Mayer (1995) in proposing the curriculum design effort called Earth Systems Education, not just for a narrowly defined Earth science course, but for the entire secondary school science curriculum. We suggest that such a curriculum could replace the "layer cake" of Earth science, biology, chemistry and physics in the United States and those separate courses taught at various grade levels in other countries. Using the concept of the Earth system and its processes as the organizing framework, basic physical and chemical principles can be learned by the student in a context of intimate importance, the student's habitat. Thus the basic principles of science can be taught more meaningfully and thus be more easily understood and retained. Using such a conceptual approach to the organization of curricula might also avoid one of the fatal elements in past attempts to integrate the science curriculum, the competition between representatives of each of the science disciplines for their 'rightful' place within the curriculum.

When it appeared that science curriculum restructuring efforts in the United States might once again ignore planet Earth, a conference of geoscientists and educators was organized by the American Geological Institute and the National Science Teachers Association with support from the National Science Foundation. It took place in Washington, DC in April 1988. The forty scientists and educators, including many scientists from the agencies responsible for the Bretherton Report, met over a period of five days. Through small group interaction techniques they developed a preliminary framework of four goals and ten concepts from the Earth sciences that they felt every citizen should understand (Mayer and Armstrong, 1990). Through the work of the conference participants and subsequent discussions with teachers and Earth science educators at regional and national meetings of the National Science Teachers Association, a new focus and philosophy for science curriculum emerged under the label, Earth Systems Education (Mayer, 1991).

In Spring of 1990, the Teacher Enhancement Program of the National Science Foundation awarded a grant to The Ohio State University and the University of Northern Colorado for the preparation of leadership teams in Earth Systems Education--PLESE, the Program for Leadership in Earth Systems Education. The objective of the program was to infuse more content regarding the modern understanding of planet Earth into the nation's K-12 science curricula. In preparation for this program, the PLESE planning committee met in Columbus in May 1990, to develop a conceptual framework which would be used to guide the content and philosophy of the program. Input for their work included the Project 2061 report (AAAS, 1989) and the results of the April 1988, conference. Over a period of five days the committee developed a Framework for Earth Systems Education consisting of seven understandings (see figure 1). These understandings provided a basis for the PLESE teams to construct curriculum guides for their areas of the country and for selection of existing materials for implementing Earth systems education in their areas. The PLESE Planning Committee intentionally arranged the understandings into a sequence to draw attention to the importance of the first two understandings especially since they are seldom if ever given importance in traditional science curricula.

Table 1. Framework For Earth Systems Education

Understanding #1: Earth is unique, a planet of rare beauty and great value.

- The beauty and value of Earth are expressed by and for people through literature and the arts.
- Human's appreciation of planet Earth is enhanced by a better understanding of its subsystems.
- Humans manifest their appreciation through their responsible behavior and stewardship of subsystems.

Understanding #2: Human activities, collective and individual, conscious and inadvertent, affect planet Earth.

- Earth is vulnerable, and its resources are limited and susceptible to overuse or misuse.
- Continued population growth accelerates the depletion of natural resources and destruction of the environment, including other species.
- When considering the use of natural resources, humans first need to rethink their lifestyles, then reduce consumption, then reuse and recycle.
- By-products of industrialization pollute the air, land, and water, and the effects may be global as well as near the source.
- The better we understand Earth, the better we can manage our resources and reduce our impact on the environment worldwide.

Understanding #3: The development of scientific thinking and technology increases our ability to understand and utilize Earth and space.

- Biologists, chemist, and physicists, as well as scientists from the Earth and space science disciplines, use a variety of methods in their study of Earth systems.
- Direct observation, simple tools, and modern technology are used to create, test and modify models and theories that represent, explain, and predict changes in the Earth system.
- Historical, descriptive, and empirical studies are important methods of learning about Earth

CHAPTER 2: A CASE HISTORY OF SCIENCE AND SCIENCE EDUCATION POLICIES

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1. INTRODUCTION

In this chapter we examine the apparent link between the history of national science priorities and the nature of the science curriculum in one country, the United States of America. We suspect that equivalent links can be found in most other countries, especially those that have aspired to some form of international leadership in politics and commerce. We document here how national priorities in the United States and the resulting political structure of the science establishment over the past century have resulted in a representation of the nature of science in school science curriculum that is inconsistent with the challenges facing the science establishment in the post Cold War world. Especially influential has been the need to develop a source of science and engineering man power and the technology essential for maintaining a strong national defense and an economically competitive business community. Science curricula are heavily influenced by the nature of the physical sciences since they have been successful in providing the scientific foundation for establishing and maintaining a powerful military and industrial/commercial capability.

Stephen Gould (1986), Agassiz Professor of Zoology at Harvard University, describes our science education and its methodological emphasis as follows:

> Most children first meet science in their formal education by learning about a powerful mode of reasoning called "the scientific method." Beyond a few platitudes about objectivity and willingness to change one's mind, students learn a restricted stereotype about observation, simplification to tease apart controlling variables, crucial experiment, and prediction with repetition as a test.

He goes on to point out that science curricula fail to provide a background in an essential component of the system sciences, that of history. In fact, they condition students to feel that a science that focuses on description and one in which experiments cannot be conducted is not science at all.

> These classic "billiard ball" modes of simple physical systems grant no uniqueness to time and object--indeed, they remove any special character as a confusing variable--lest

V.J. Mayer (ed.), Global Science Literacy, 25–35.

> repeatability under common conditions be compromised. Thus, when students later confront history, where complex events occur but once in detailed glory, they can only conclude that such a subject must be less than science. And when they approach taxonomic diversity, or phylogenetic history, or biogeography--where experiment and repetition have limited application to systems in toto--they can only conclude that something beneath science, something merely "descriptive," lies before them.

Gould effectively portrays the type of science presented in American classrooms, its character developed through a century when our national focus has been on war and economic competition. He describes, in essence, a science curriculum modeled on physics and largely ignoring the contributions to science of both the methods and knowledge of the system sciences.

In this chapter we briefly discuss 'reduction' science and 'system' science methods. In Chapter Three we provide a more extensive discussion of the relative nature of these two aspects of science methodology as ends of a continuum of methods of science. We use the term 'reduction' when referring to the methodology of physics, chemistry and some of biology. It is a simple and descriptive term to use in characterizing the science methodology and the resulting product of these sciences. It informs on two levels, first methodological. Practitioners of these sciences seek to isolate single variables and test one against another, the 'billiard ball' analogy of Gould. In other words, they attempt to reduce the number of variables to be tested so that controlled experiments can be conducted. On another level, that of the information provided by the science, it is also descriptive. Physics especially, seeks to reduce the complexity of the world down to its simplest and most powerful elements such as time, gravity, nuclear attraction. In contrast the system sciences, which include the Earth sciences and ecology, attempt to study a system whole and over time. Thus, in Gould's terminology the system sciences are characterized by history and diversity of variables. Description and sequencing phenomena in time are fundamental. Science methodology is complex and at times each of the science disciplines calls on a variety of methods to elucidate an object or phenomenon, from reduction methods at one end of a continuum of methods to the system methods at the other end

Through the Cold War epoch especially, school science curricula, reflecting a national effort to recruit talented people into science, have emphasized the use of the investigative methods of chemistry and physics and the understanding of the natural laws and principles these sciences have developed. The curricula seldom make reference to the Earth system in which these laws and principles function nor do they include the science methodology of the system sciences. This has helped to create in the public mind a hierarchy in science with physics at the top thus contributing to a social and political climate in the USA where physics is seen as the embodiment of all science or by some, the only science. It is also an attitude often expressed in the physics community itself. Perhaps this attitude is best represented by a statement attributed to Ernest Rutherford (1871-1937) a prominent physicist, "All science is either physics or stamp collecting." Although Rutherford was English and did his research in England and Canada early in the last century, the attitude toward other sciences as expressed in this statement can often be found in the American physics community today.

Obviously not all science offered in the secondary schools is either physics or chemistry. Social and health concerns have provided a prominent place in school curricula for biological science concepts. Increasingly however, biology is being represented by the reduction approaches and molecular content rather then the ecological or systems approaches and content. Minimized or ignored in school science curricula is the study of how basic physical, chemical and biological processes act within their natural domains, the Earth systems of which they are functioning parts, and the science methods that can effectively study these processes. Adapting the science curriculum to represent the science methodology and conceptual contributions of all sciences, therefore, requires the inclusion of science methodology and content that goes beyond the approaches and content of the physicist and chemist. Instead the future students of science should also examine large systems as they normally function in nature. They need to learn how scientists collect and analyze observational data now aided by satellite and computer technology. They should learn how to use some of that data themselves in developing scientific explanations of natural phenomena just as they examine physical principles in laboratory situations. Only by participating in this type of 'system science' will they be prepared as citizens to evaluate its results and its power in informing them of the current status of our planet and potential solutions to environmental and social problems. Curricula that include systems oriented science can correct the current imbalance in secondary science programs and demonstrate to students how basic processes operate within systems and how systems are changed through human interventions.

After all of the money and time that has been invested in science curriculum restructure over the past decade, why is the result still deficient in the system sciences? Here we briefly review the development of science in the USA from the end of the Civil War to the present in support of our contention that national priorities shape a politics of science which in turn influences not only what science is practiced but also how science is represented in school curricula. We also take a brief look at the development of science curricula, which seems on the surface at least, to bear out our contention that the politics of science also influences the focus and content of science curricula. We then discuss briefly the neglect of system vis-a-vis reduction science. A more detailed examination of the philosophical basis for our arguments has been made in Chapter Three where we also relate system science to Eastern thought and suggest that it is complementary to certain Asian cultures. It therefore reflects a science more international in scope and culture than that currently in science curricula in most countries. We argue for changes that we believe are consistent with the directions being taken by modern national and international priorities for science and the emerging new politics of science.

2. A SHORT POLITICAL HISTORY OF AMERICAN SCIENCE

A discussion of the political history of science in the United States over the past century illustrates the effects of national priorities, often for defense, on our science establishment and the public's opinions regarding science. The era following the

Civil War in the USA was the time during which the foundation of American science was laid. The late 1800s was a crucial period in the Industrial Revolution in the USA. There was a need for natural resources to support the developing industrial base for what would become one of the world's most vibrant economies. Kelves (1987) in his history of American physics points out that it was the Earth scientists who were at the apex of political and scientific influence during this period. Clarence King was perhaps the preeminent American scientist of his time. He, John Wesley Powell and Charles Walcott, are a few of the Earth scientists who were the science power brokers of the latter half of the 19th century and on into the early 20th century. King conducted the Geological and Geographical Exploration of the Fortieth Parallel (Wilkins, 1988). Powell was especially effective in raising the federal funds necessary for these explorations. He was responsible for several other Western expeditions, and also the political maneuvering that resulted in the establishment of the United States Geological Survey (Stegner, 1954). The nature of the science conducted was descriptive and historical with little or none of the reduction later to typify American science. Kelves (1987) compares the two sciences of geology and physics as they coexisted during the late 1800s. The Geological Survey had won the prestigious Cuvier Medal awarded by the French Academy of Science for its collective work. Geology in the United States in general had the respect of the Europeans for the quality of its science whereas physics was poorly done in the United States. There were more geologists then physicists and a higher proportion of the geologists were theorists (p. 37).

Kelves (1987) points out that this preeminence of geology was in part the result of the considerable political influence exerted by Powell and other Earth scientists to secure the governmental funding necessary for the growth and institutionalizing of their science (p. 49-55). This achievement was influenced by the priorities of a country deep into the Industrial Revolution and in need of the natural resources of its domain even as later changes in the science establishment were influenced by war and its imperatives. Further evidence of the relative status of the Earth sciences in the scientific establishment of the late 1800s and early 1900s is found in the leadership of the National Academy of Sciences and the American Association for the Advancement of Science (Stegner, 1955; Wilkins, 1988).

According to Kelves (1987), the changes in the American science establishment began during the later stages of World War I when the requirements for winning that war became a priority for our political and industrial establishments. The Bureau of Mines was awarded substantial money by the Army to supervise more than seven hundred chemists working on chemical weapons (p. 132). ". . . observers then and since have, with considerable justification, called World War I 'a chemist's war' " (p. 137).

With the sinking of the Lusitania came an urgent concern, the growing German submarine threats to American shipping. With the failure of Thomas Edison's inventive genius to find a way to locate enemy submarines, the War Department called upon the academic physicists for help. They provided the conceptual knowledge of sound waves and their transmission through water which they used in the successful development of sonar (Kelves, 1987, p. 121-131). Subsequently, the federal support of science shifted to physicists and chemists with their sciences consequently becoming the major power centers in American science. With the onset of the Second World War more and more support flowed to the physical scientists and along with the money went prestige and political influence. Kelves states that, ". . . this was a war of physicists" (p. 320). The Los Alamos generation, brought to the forefront by its development of the Hiroshima and Nagasaki bombs, " . . . was dominated by physicists who seemed to wear the 'tunic of Superman,' in the phrase of a *Life* reporter, and stood in the spotlight of a thousand suns" (p. 334).

The ascendancy of the physical scientists in the mind of the public was matched by their ascendancy to the top of the hierarchy of science. The physical sciences, physics and chemistry and their science methodology best served the needs of the political and industrial establishments, advised by the same physical scientists, into and through the Cold War period. Thus it is Feynman, Teller, Alvarez and their colleagues and successors who have had the political influence to affect the direction of science. (Alvarez, 1987; Panofsky, 1999). Their success in assisting in the winning of the Second World War for the Allies and their work on nuclear physics during the Cold War placed their methodology at the helm of good science.

3. CHANGES IN SECONDARY SCHOOL SCIENCE CURRICULA

A rough parallel can be drawn in the evolution of secondary school science curricula over the same time period. In tracking the fate of the system sciences in the nation's curricula we use that of the Earth sciences. In the future more detailed research might also focus on the fate of ecology as a component of biology curricula. The Committee of Ten of the National Education Association, in 1893, presented its recommendations for the nature and content of science courses to be offered at the senior high school level. Its report, along with others directed at establishing requirements for college entrance, heavily influenced high school administrators and teachers in the development of their science courses (DeBoer, 1991, p. 40-50). These developments eventually lead to a sequence of science courses commonly offered in high school. They lead off with physical geography at the 9th grade, followed by biology in the 10th, chemistry in the 11th and physics in the 12th. This sequence has been labeled the 'layer cake' approach and, except for physical geography, has become the traditional sequence of offerings at the secondary level in the USA.

A topic outline for the physical geography course of the turn of the century would outwardly bear a very strong resemblance to that of a modern 9th grade Earth science course heavily oriented toward geology and geomorphology topics. In 1900 more than 20 percent of the high school population was studying physical geography, becoming the most frequent science course completed by high school graduates. Following World War One it gradually disappeared from high school curricula. In part it was replaced by general science under the influence of the progressive education movement. During World War Two, biology came to dominate as a 9th grade offering for more talented students. By 1950 most schools had eliminated physical geography from the curriculum, with the exception of New

CHAPTER 3: THE PHILOSOPHY OF SCIENCE AND GLOBAL SCIENCE LITERACY

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1. INTRODUCTION

There has been a significant amount of discussion in the science education literature concerning needed changes in the science curriculum. These discussions have centered on several proposed reasons for change. One is based on the relative performance of a nation's children on international tests, the major political driving force behind the efforts of the American Association for the Advancement of Science (AAAS) and the National Academy of Sciences (NAS) in the United States to produce guidelines (AAAS, 1989; NAS, 1996) for the improvement of science curricula targeted as contributing to these low test performances (Bracey, 1998; Wang, 1998).

Another argument comes from science educators engaged in multi-cultural education in the USA and some science educators in non-Western countries and is based partly on low student performances in science and low representation of women and American minorities in scientific careers (Klotz, 1993; Ogawa, 1995; Stanley and Brickhouse, 1994). Black and Atkin (1996, p. 16-17) in a study of curricula from 13 countries sponsored by the Organization for Economic Co-operation and Development (OCED) identified a concern with inclusiveness and equity as a driving force for curricular reform in science, mathematics and technology. The Ministry of Education, Science and Culture (Monbusho) in Japan, has expressed concern regarding the nature of the Japanese curriculum generally and its role in developing more creative, independent and problem solving characteristics among Japan's citizens (Monbusho, 1997, p. 9).

A major factor is the concern among scientists and science educators of several countries, including Great Britain, of the need for science curricula directed toward developing the understanding among the general citizenry of the important processes and concepts of science (Millar and Osborne, 1998; Black and Atkin, 1996). This contrasts with curricula developed in the USA in the 1960s and 1970s and other countries as well that seem to be designed to attract students into the science and technology professions. This more recent focus upon scientific literacy has also been the guiding philosophy of the efforts of the AAAS and the NAS in the development of curriculum guidelines for schools in the USA.

V.J. Mayer (ed.), Global Science Literacy, 37–49.

Although these discussions and contributions are of interest and importance in academic dialogue and curriculum restructure, they do not get to the core of what we believe to be a major challenge for the school science curricula of the future. What is apparently absent from current restructure efforts is any substantive analysis of the future needs for science in the post-Cold War era, how it must, and is, adjusting to these new priorities, and the implications for an adequate representation of science in the world's pre-college science curricula. We do see a substantial reference to technology and its relation to science and the importance of its inclusion in science curricula. The argument made for its inclusion is usually to demonstrate the relevance of science to students (AAAS, 1989; Atkin, 1998; Millar and Osborne, 1998; Monbusho, 1997). This, however, can also be seen as carrying on a role for pre-college science in preparing and recruiting students into science and technology careers in support of international commercial competition, one of the driving motives for curriculum restructure found in the OCED study (Black and Atkin, 1996, pp. 14-16).

In reviewing all 23 programs for common factors influencing curricular reform, Black and Atkin (p. 60) also conclude that the role of academic scholars in defining the 'basics' of science and mathematics from research results and their importance in curricula for all students was found in only one program. That was in Project 2061, completed and published in 1989, toward the end of the Cold War. It drew upon a science, mathematics and engineering establishment however still embedded in the science politics of war and economic competition.

2. POST-COLD WAR CHALLENGES TO SCIENCE AND SCIENCE EDUCATION

The end of the Cold War and the beginning of the era of globalization are factors that should bring substantial reexamination of the historical and philosophical foundations of science upon which current science curricula have been established. Such a reexamination would have implications for the content and focus of future curriculum efforts whether directed at developing curricula to attract and prepare future scientists and engineers, or for the general education of a citizenry in science. Supporting this contention is the fact that some within the scientific and political communities are working to refocus the objectives of a science establishment employed for much of the last century in developing the scientific foundation for the conduct of war (Kelves, 1987) and commercial competition perhaps starting as far back as the Industrial Revolution in Britain. As the goals and objectives of the science establishment are reshaped, so must science curricula be changed to reflect the modern priorities of science.

With the scientific documentation of the environmental and social problems infecting developed and developing nations, and indeed the Earth system, many scientists and political leaders feel that science must be redirected toward the solution and prevention of these problems. In Chapter Two we have discussed the viewpoints of George E. Brown, Jr., representative in the United States Congress from California until 1999, and a longtime leader in science legislation, and Lubchenco (1998), in her presidential address to the AAAS membership. Both have concluded that the priorities for science must change so that it can more effectively confront the social and environmental problems brought on in large part by the side effects of policies in science and technology during the past century. Educators should be leaders in redefining the nature of the pre-college science curriculum and in this way participate in reshaping the political structure and objectives of the science establishment. To do this, however, we must have a clearer and broader understanding of the nature of science, its history and its current structure.

3. THE HISTORY AND PHILOSOPHY OF SCIENCE

Matthews (1994) believes that there are important lessons to be learned by science teachers from the history and philosophy of science. Such knowledge will be essential for the improvement of science teaching. We endorse his position with a warning to be alert concerning the nature and perspective of much that has been written about the history and philosophy of science. Almost invariably, those who study and write about it focus their attention on the physical sciences, physics and chemistry. This provides a view of the world that is mechanistic and deterministic, and of a method of science in which scientific constructions are developed of components isolated from their natural systems. Much of what is written about the history and philosophy of science is in reality the history and philosophy of physics. Arthur Strahler (1992) in his introductory chapter on the nature of science states it thus:

> One difficulty is that the giants in science and philosophy are prone to restrict the scope of science rather severely, usually to physical science, and even as narrowly as to nuclear and quantum physics alone. We must on the other hand, cover a large area of natural science quite far removed from the ideal behavior of matter on a subatomic scale. Besides dealing with the origin and physical evolution of the universe--a field that does indeed rest in large part on principles of theoretical physics--we must include the geological and biological evolution of our own planet Earth over a time span of billions of years. Here we will find extremely complex aggregations of matter that have long and involved histories of continuous development. Scientists who investigate these historical areas of knowledge need to adopt specialized views of science. (p. 7)

Seldom do writers on the philosophy of science draw from the historic and interpretive sciences of geology or ecology. An exception, in addition to Strahler, is Robert Frodeman (1995) a researcher in the philosophy of science who possesses a graduate degree in geology. As evidence of the neglect of what he terms the 'interpretive and narrative' forms of science he points out that while philosophers of science widely acknowledge the crucial importance of the Copernican Revolution in our conception of space, they ignore the even more significant contributions of Hutton and Werner in the development of the concept of the great age of the Earth, geological time or what is popularly referred to as 'deep time'.

Strahler is a geologist who has written a book for science majors entitled *Understanding science*. He categorizes areas of knowledge as belief, such as religion and political ideology, and the empirical sciences. The empirical sciences, through research, construct reliable but not infallible knowledge of the real world and include explanations of the phenomena (p. 8). Empirical science differs from belief in that it " . . . must follow rules of sound logic and must make use of mathematics" (p. 13).

Strahler, in order to clarify the scope of science more broadly than is typical in the writings of the physical science community, describes three fields of empirical science (p. 13): 1) the physical sciences which deal with the nature of matter and energy and largely utilize controlled experiments conducted within laboratories; 2) several complex inorganic sciences requiring observation of nature outside of laboratories such as oceanography and geology, and; 3) the biological sciences which deal with living cells and their aggregations. Unique to the second and third fields is their reliance upon the history of events spread over vast periods of time. Strahler and other Earth scientists use the term 'history' as the sequence of events that have occurred over a defined period of time, as in the 'history of dinosaurs', and the physical and biological processes that they mark. It should not be confused with and does not refer to the nature of investigation used by historians in interpreting human history.

In a later chapter, he goes into more detail in describing the various areas of the natural and social sciences. Under what he calls the pure sciences he lists the natural and social sciences, and under the natural sciences, the physical sciences (chemistry and physics), the macrocosmic/inorganic sciences (including geology and meteorology among others) and the biological sciences. He characterizes the physical sciences as atomistic, reductionistic, timeless, and universal. They are,

> ...set apart from the other natural sciences on grounds that they seek to understand the basic nature of matter and energy and their interactions; while the others study complex and unique systems of matter and energy that occupy specified and fixed positions in time and space.
>
> ...they are concerned with general (universal) laws that can be expressed mathematically or by other symbols. The method of the physical sciences is almost entirely experimental, including not only laboratory experimentation but also repeated instrumental observations in a natural environment. (p. 77)

The macrocosmic/inorganic sciences and the biological sciences (MIS/BS) are complex/historical, synthetic/emergent; organicistic, time bound, and particular.

> Besides dealing with highly complex structures, the MIS/BS investigate complex time sequences of events, something we do not find in basic physics and chemistry. Examples are the life cycle of an individual of a plant or animal species, the evolution of life on earth over hundreds of millions of years, or the birth and life history of a star or galaxy. Thus, the quality of history pervades MIS/BS. (pp. 80-81)

We have presented a condensation of his categorization of the natural sciences, not to suggest that there are different sciences, but to point out the narrowness of the traditional discussions of the history and philosophy of science in the science education literature. Such discussions normally rely on what Strahler categorizes as the physical sciences. Their narrowness, we believe, has also resulted in a narrowness of the representation of science in school curricula. As Duschl (1990, p. 24) has pointed out, the physical sciences have had an overriding effect on the nature of science curricula, not only in the United States and Japan, but worldwide. Yet, it is the MIS/BS sciences and their methodology that may make the difference in effectively facing the environmental and social problems that should become the major topics of scientific inquiry in the future.

3.1. The nature and importance of system science

Frodeman (1995) describes the method of scientific reasoning used by geologists. He makes the argument that this methodology is related to but significantly different from that used by the physicist. In part, this is because little of interest to geologists can be done in the laboratory under controlled conditions. Investigations go on in the natural environment with only minor confirming types of experiments that can be done in the confines of a laboratory. Geologists work in a historical science where descriptions of events occurring in the past need to be made by analogy with current processes. Many variables, some present temporally, others acting historically, must be considered when drawing conclusions. As a result, geologists use an interpretive and narrative form of reasoning. It is this type of reasoning, however, which he concludes will be of greatest value as science explores current and future environmental and social challenges. Primarily through this type of reasoning can we gain the knowledge to reduce the effects of and adapt to global warming, correct problems caused by water and air pollution, and solve some of the social problems in the post Cold War era.

Most Earth scientists would agree with the nature and importance that Frodeman ascribes to the intellectual processes they use. For example, Walter Alvarez (1997) a geologist and son of Luis Alvarez, Nobel Laureate in Physics, compares the processes used by the physicists and Earth scientists in the preface of his book written for a general audience. In discussing the science that has led to the understanding of the great Cretaceous extinction he states:

> It is also the story of how geology and the other disciplines which study the Earth have emerged as fully mature sciences, distinguished by their inherently interdisciplinary nature, by the complexity of their subject matter, and by the obvious requirement to move from reductionistic to holistic science in order to achieve their central goal of understanding the Earth. Through the twentieth century, physics and chemistry, and recently molecular biology, have made enormous strides in understanding Nature by the analytical approach--by reducing problems to their fundamental components and studying these components in isolation. In the twenty-first century, science will be in a position to begin putting the pieces together, in order to seek a synthetic or holistic understanding of Nature. The Earth sciences are inherently synthetic and are therefore uniquely placed to lead this development. (pp. x-xi)

Lazlow (1972), a philosopher, describes what he terms 'system science' in some detail. He starts by redefining for his purposes the usual categories of nature as discussed by philosophers and historians of science--inorganic, organic and social--as sub organic, organic and supra organic. This therefore implies levels of organization of nature (p. 30) instead of distinct compartments or categories of objects or processes and makes the discussion of nature more amenable to a systems approach. In sub organic he includes phenomena such as atoms which, although

CHAPTER 4: THE 'EXPLANATORY STORIES' APPROACH TO A CURRICULUM FOR GLOBAL SCIENCE LITERACY

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1. INTRODUCTION

In the current debate about future revision of the science curriculum in England and Wales, a document central to the discussions is *Beyond 2000: Science education for the future* (Millar and Osborne, 1998). This argues for an education for all pupils in scientific literacy. Such an education would be based on a series of carefully chosen 'explanatory stories' that take key 'big ideas' in science and explain these in a rounded, relevant and interesting way that highlights their importance in current scientific understandings and developments. Such an approach mirrors many of the aims and objectives of Global Science Literacy (GSL) and can be developed to further these aims even more effectively.

Breadth, balance, even more relevance, and more scope for the development of GSL objectives, would be added to the *Beyond 2000* proposals by adding Earth science-related stories to the list of 'explanatory stories' provided as examples in the document. This chapter provides an exemplar of how such a story entitled, 'The dynamic Earth's crust' might be developed. The story is written in an accessible, relevant and interesting way that draws together the threads of the processes that have affected our planet's evolution and will have ramifications for the future of the Earth. It is dissected to emphasize the scope for developing GSL approaches and links with other areas of science. A variety of teaching and learning activities is suggested to illustrate the range of skills and perspectives that can be taught in this way. Such a story could provide a powerful vehicle for the development of scientific understanding in young people, beyond the narrow confines of science as it is currently taught in many classrooms and laboratories. It would illustrate the key role that science can play in the safeguarding of our planet for the future.

2. REVISING THE NATIONAL CURRICULUM FOR SCIENCE

The National Curriculum (NC) is the central focus of all government schools in England and Wales for children between the ages of 5 and 16 and has now been in place for ten years. It includes the three core subjects of mathematics, English and science, and a number of foundation subjects including geography, technology, languages, physical education, etc. There were a large number of changes to the detail of the NC in the early years, such that, in science, seven different versions of the National Curriculum for Science (NCS) appeared at different times of which three were actually implemented. Since all this change caused significant problems

V.J. Mayer (ed.), Global Science Literacy, 53–78.

to the successful implementation of the National Curriculum in schools, in 1995 a five-year moratorium to changes was called. This gave five 'change-free' years for schools, as far as NC detail was concerned and five years to prepare for the changes due in September 2000. In the event, only a limited revision was carried out in 2000, with a more comprehensive review being envisaged for 2005.

In the build up to the September 2000 changes in the National Science Curriculum, a series of debates took place. The most influential of these were:

- those generated by the Association for Science Education (ASE) that resulted in the document *Science education for the year 2000 and beyond* (ASE, 1999);
- those that formed part of a seminar series funded by the Nuffield Foundation. The document produced as a result of the Nuffield seminar discussions was called *Beyond 2000: science education for the future* (Millar and Osborne, 1998).

3. THE GLOBAL SCIENCE LITERACY PERSPECTIVE

The global science literacy approach (GSL) as described in the first section of this book, focuses on:

A conceptual rather then disciplinary organization of curricula. Instead of arranging science curricula according to units or courses organized around the contributions of each of the traditional disciplines of science, GSL recommends a unified, conceptual organization of curricula. The organizational concept is the Earth as a System and its involvement in larger systems. This concept or set of concepts, after all, is the subject of all science investigations.

A broader encompassing of the spectrum of scientific methodology beyond the reductionism characteristics of current curricula. GSL includes a significant treatment of the systems methodologies of the ecologists and Earth scientists.

An inclusion of aesthetic aspects of science and its subject, the Earth System. This inclusion recognizes the incentives of many scientists in their study of Earth and brings science close to its students and their diverse cultures. It recognizes the aesthetic feelings and reactions to Earth system phenomena that are often expressed in the arts, literature and music of their nation or culture.

A recognition of the unique qualities of science and its ability to develop procedures and languages that bridge cultural and linguistic boundaries. As a component of curricula, knowledge of the culture and procedures of science can therefore help to achieve the objectives of Global Education (a Social Studies curriculum construct) thereby assisting international and inter-cultural understanding.

Science as a way of understanding ourselves as an interacting component of the Earth system that we all share and inhabit. This concept of humanity as a part of nature is consistent with many elements of Eastern thought and contrasts with the western conception of man as created separately and therefore apart from nature.

The uses of appropriate technology to assist our understanding of Earth and to conserve Earth resources. GSL does not view science as a basis for the development of technologies for defense or economic competition; a view of science that seems implicit in most of the world pre-college science curricula today.

4. THE DEBATE ON THE FUTURE FOR SCIENCE EDUCATION – AND ITS LINKS WITH GLOBAL SCIENCE LITERACY

4.1. 'Science education for the year 2000 and beyond' and Global Science Literacy

The ASE document *Science education for the year 2000 and beyond* (ASE, 1999) was produced as the result of a wide-ranging debate across the science educational community. A constructive contribution to the debate was provided by the Earth Science Teachers' Association (Thompson, 1996). The document, produced as a result of the debate, lists a series of aims, as follows. The first two are considered important at all ages.

- The development of curiosity, sensitivity, social responsibility, motivation and independence in learning, when dealing with living things, the environment and the applications of science.
- The development of investigative observational and manipulative skills.

The following aims are considered to show increasing emphasis as learners get older.

- The development of scientific terminology and an understanding of key scientific ideas.
- Understanding of the generation, evaluation and use of evidence in making decisions, solving problems and considering scientific, personal, social and environmental issues and ethical implications.
- Understanding of the tentative nature of scientific knowledge and the use of theories and models in explanation.

The document notes that the science curriculum should focus on 'the place of science in our lives' in a way that encompass a holistic view of science education and enables learners:

- to participate fully in a technological society as informed citizens who understand the nature of scientific ideas and activity and the basis for scientific claims, and
- to develop intellectually and morally through experiencing the richness and excitement of exploring the natural and physical world.

This holistic view could be provided by the GSL focus on Earth as a system that would particularly offer the richness and excitement of exploring the natural and physical world and would effectively deal with living things, the environment and the applications of science. GSL emphasis on appropriate technology would form a key aspect of the pupil's view of a technological society. Both the ASE and GSL documents emphasize that pupils should see science as a way of understanding ourselves in the scientific context of the Earth environment.

Part of the ASE document (p. 4) focuses on the selection of key scientific ideas that should be included in the science curriculum. It stresses that these should:

☐ enable learners to make sense of science;
☐ have global significance (not a list of facts);
☐ have personal significance to the learners;
☐ be supported by practical activities and have applications; and
☐ map progression in a core of knowledge and understanding that enables children to understand how ideas develop.

The document adds: 'A number of the key scientific ideas benefit from being developed through a storyline approach'. The 'storyline approach' is explained in more detail below. All the points listed could be addressed effectively through a GSL perspective.

4.2. 'Beyond 2000' and Global Science Literacy

The Nuffield document *Beyond 2000: science education for the future* (Millar and Osborne, 1998) concludes with ten recommendations to guide future revisions of the NCS. Some were intended for the limited revision of the NCS in 2000 and some for a more comprehensive revision in 2005. The two main Nuffield recommendations relating to 2000 have now been incorporated into the revised version of the NSC. Thus, it is likely that a number of the recommendations relating to 2005 will also be incorporated at that time. Key recommendations of the Nuffield document, that relate to Global Science Literacy (GSL) but have yet to be implemented include:

- **Recommendation 1:** The science curriculum from ages 5 to 16 should be seen primarily as a course to enhance general 'scientific literacy'.
- **Recommendation two:** At Key Stage 4 (14 - 16 year olds), the structure of the science curriculum needs to differentiate more explicitly between those elements designed to enhance 'scientific literacy' and those designed as the early stages of a specialist training in science, so that the requirement for the latter does not come to distort the former.
- **Recommendation 4:** The curriculum needs to be presented clearly and simply, and its content needs to be seen to follow from the statement of aims (above). Scientific knowledge can best be presented in the curriculum as a number of key 'explanatory stories'. In addition, the curriculum should introduce young people to a number of important ideas about science.
- **Recommendation six:** The science curriculum should provide young people with an understanding of some key ideas-about-science, that is, ideas about the ways in which reliable knowledge has been, and is being, obtained.
- **Recommendation 7:** The science curriculum should encourage the use of a wide variety of teaching methods and approaches. There should be variation in the pace at which new ideas are introduced. In particular, case studies of historical and current issues should be used to consolidate understanding of the 'explanatory stories' and of key ideas-about-science, and to make it easier for teachers to match work to the needs and interests of learners.

In the light of these recommendations and those of the ASE document (ASE, 1999), it is likely that an NCS for the 'scientific literacy' of all children will be considered that may be based on some key 'explanatory stories', which include case studies of historical and current issues.

5. THE 'EXPLANATORY STORIES' APPROACH

The document *Beyond 2000* (Millar and Osborne, 1998) recommends that the science curriculum be presented, at least in part, through a series of 'explanatory stories'. The authors (p. 13) describe these as accounts that have broad features which interest and engage pupils and are able to communicate ideas in a way that makes them coherent, memorable and meaningful. The 'explanatory stories' are not fiction, but use the narrative form to present the ideas as a rounded whole. The stories (p. 13–14):

- emphasize that understanding is not of single propositions or concepts, but of inter-related sets of ideas that provide a framework for understanding;
- help to ensure that the central ideas of the curriculum are not obscured by the weight of detail so that both teachers and pupils can see clearly where the ideas are leading;
- portray the sort of understanding that one would wish young people to develop through studying the science curriculum.

The authors developed the 'explanatory stories' approach recommended in the 'Beyond 2000' document over several years. An initial impetus came from a report published by Ogborn, Brosnan and Hann (1992) that was based on a paper produced by Ogborn in 1991 (Ogborn, 1991). In these publications, the authors explored the use of explanation in science and used the term 'history' or 'explanatory history'. A 'history' is the account of a scientific situation (or 'world') from which an explanation for a scientific phenomenon is derived. This idea was built upon by Arnold and Millar (1996) in a paper containing the phrase 'Learning the scientific "story"' in the title. The authors (p. 250) state that 'Our use of the term (story) is intended to convey the complex and interrelated set of ideas which constitutes the accepted scientific explanatory framework for a particular domain of science education' before going on to discuss the 'story' of elementary thermodynamics.

This approach was further discussed by Millar (1996, p. 13) in arguing that there are a number of 'powerful models' at the heart of science that provide explanations for natural phenomena. He described these explanations as a 'story' or 'mental model' that provides a means of thinking about what is going on. He went on to 'nominate' a range of suitable models, including: the atomic model of matter; models of the solar system; a model of radiation transmission; 'field' models (gravity, magnetism, electricity); the germ theory of disease; the gene model of inheritance; Darwin's evolutionary theory; and models of the evolution of the Earth's surface (rock formation, plate tectonics). Millar felt that these models would address a number of key ideas, including those of size, scale, distance, time, cycling

CHAPTER 5: COOPERATIVE LEARNING: A BASIC INSTRUCTIONAL METHODOLOGY FOR GLOBAL SCIENCE LITERACY

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1. INTRODUCTION

The development and implementation of GSL curricula in countries around the world could potentially have a positive impact on citizens' worldviews and understanding of other cultures. Citizens exposed to such curricula should be able to engage more effectively in a world approaching globalization through politics and commerce. Importantly for the desired outcomes of GSL, those who have internalized the curricula should see Earth's environment as one without borders. They should see the need for working together for the common goal of a sustaining and sustainable environment.

One of the most important issues in world affairs is how to establish cooperation in an atmosphere in which competition has been the norm for centuries. When the world was not competing for land area with which to expand its empires, it was competing for the wealth of the lands. When individuals were deprived of competition, as in communist regimes, the quality of their performance was prone to decline, for the measure of excellence ceased to be based on comparative quality. As advertisers compete for buyers, and as organizations compete for members, there are expressions of one entity's benefits compared to the other. When many are competing, there must be "play-offs" to see who is ultimately the best.

Education has unfortunately been no different. Science educators, politicians, the mass media and parents around the world have taken great interest in the tests comparing students' science and mathematics achievement in different countries. No matter that the educational systems in those countries are very diverse, and individual goals may be culture-bound; higher scores are interpreted by most as signaling "better" science. Should we compete for science literacy, or cooperate to achieve it?

In classrooms, we have competed against an arbitrary scale determined by a person assumed to know "the answers" to questions. If all students excelled, the questions must not have been difficult enough. A teacher who assigns a large number of high grades is assumed not to be teaching on a high enough level. Low grades are a sign of rigorous instruction, through which the ignorant are raised (not quite) to the level of their master. All are provided with the information; those who can remember it for the examination are the winners. Thus, one student is at the head of the class, because s/he competes best. How, then, is a student to be taught the value of *cooperative* learning, when the measures of excellence are the traditional *competitive* ones?

V.J. Mayer (ed.), Global Science Literacy, 79–92.

2. VALUES OF GROUP LEARNING/COLLABORATION FOR LEARNING SCIENCE

Imagine how different the world would be if people were taught from the first days of life that the sharing they do on the playground would also serve them well in creating a peaceful world and an educational system fostering human development in its most positive patterns! In the essay, "All I really need to know, I learned in Kindergarten" (Fulghum, 1993), we are reminded of the importance of dealing with others in a simple, forthright manner, and of the benefits that come from this behavior. Some of Fulghum's bits of wisdom with application to world cooperation are: Share everything. Play fair. Don't hit people. Clean up your own mess. Say you're sorry when you hurt somebody. My personal favorite is "When you go out into the world, watch out for traffic, hold hands, and stick together." If we work together and use our collective wisdom, we can survive potentially harmful situations.

We can also apply some of these maxims to the learning of science. We can't all know it all, so why not share information, build each other's competencies, and grow together? If we trust each other to do our best and share our talents, we not only gain allies instead of enemies; we also build up a collective body of knowledge and experience larger than our own. We have a bigger bag of tricks when it comes to figuring out the answers to complex questions, and we have a nurturing environment that will not let us quit when there is a chance for success.

In environmental education, the emphasis is usually not on competition but on accomplishment through cooperation and collective action. We teach about the Earth as a system, with interacting components that are always affecting each other (Fortner, 1991). We cannot study individual disciplines without seeing how they are connected to other disciplines. Since 1988, the Earth Systems Education program at The Ohio State University and in many other areas has been developing curriculum materials and cooperative instructional methods for the multi-disciplinary sciences of global change and other environmental issues (Fortner, 1996). The combination of curriculum development and teacher education provides schools with high profile examples of the ways humans have affected the Earth system and how they must cooperate to restore and maintain a sustainable environment for the future.

Thus, it is natural that Global Science Literacy relies on cooperative learning as a prominent feature of instruction. Slavin (1983) defined cooperative learning as referring to "instructional methods in which students of all performance levels work together in small groups toward a group goal. The essential feature of cooperative learning is that the success of one student helps other students to be successful." While the concept of cooperation in teams is not new, research is building to justify its use in instruction through cognitive and social gains, and the methodology of cooperation is consistent with goals of science in society.

In a special issue of *Theory Into Practice (TIP)*, the College of Education at The Ohio State University has focused on "Building Community Through Cooperative Learning," and that is exactly why global science literacy depends on the collaborative process. In the issue, the co-directors of the Cooperative Learning

Center at the University of Minnesota, David W. Johnson and Roger T. Johnson (1999), discuss what is and what is not cooperative learning:

> Cooperation is working together to accomplish shared goals and cooperative learning is the instructional use of small groups so that students work together to maximize their own and each other's learning. Within cooperative learning groups, students are given two responsibilities: To learn the assigned material and make sure that all other members of their group do likewise.

Assessment of student outcomes from such lessons takes into account their non-competitive nature. Thus, individual achievement is measured by portfolios, concept maps, and other alternatives to testing, and group achievement is observable as a communicated product that synthesizes the group's activities, research, or thinking about a topic. Research in many situations has shown that cooperative learning usually produces similar or greater gains in knowledge in comparison to traditional methods (e.g., Allen and VanSickle, 1984; Humphreys et al., 1982; Okebukola, 1985; Slavin and Karweit, 1985). It is important to note that social gains are included in the assessment of cooperative learning outcomes in most of the recent research (e.g. Slavin and Fashola, 1998; Stevens and Slavin, 1995). It is those aspects that are most exciting to those who look toward schools as providing teachable moments for more than just college entrance examinations.

3. TYPES OF COOPERATIVE LEARNING

Not all groups assembled in a classroom are cooperative. As Johnson and Johnson (1999) describe: There are pseudo learning groups in which students assigned to a group have no interest in or incentive for learning together, and believe they will still be ranked as highest to lowest. As a result of grouping the sum is less than the potential of the individual members; group activity hinders the learning process. Traditional classroom learning groups accept that they must work together, but group growth is not an internal goal. Some students let others do most of the work, and the workers are frustrated and feel exploited. In such cases the conscientious students would be better achievers if they worked alone, and some students do not work at all yet get marks for completion.

In a true cooperative learning group,

> students work together to accomplish shared goals. Students seek outcomes that are beneficial to all. Students discuss material with each other, help one another understand it, and encourage each other to work hard. The result is that the group is more than a sum of its parts, and all students perform higher academically than if they worked alone" (Johnson and Johnson, 1999).

Three general types of true cooperative learning have been described by Johnson, Johnson and Holubek (1998):

- Formal (for teaching specific content);
- Informal (to insure active cognitive processing of information during a lecture or demonstration; and
- Cooperative base groups (to provide long-term support and assistance for academic progress.

Cooperative learning strategies place the responsibility for learning more squarely on the shoulders of students than do the lecture-discussion strategies that dominate college classrooms. This does not imply that the responsibility of the instructional leader is diminished. On the contrary, the design of cooperative learning experiences is more difficult than lecture preparation, as it requires a high degree of advance organization, anticipation of student response, and concurrent development of meaningful applications of the subject matter, for use in assessment.

Cooperative learning has been used in many settings for many different purposes. While the beginnings of cooperative learning probably extend back to the division of labor among pre-hominids, more recent applications in education often cite the work of Johnson and Johnson (1975/1994) for the basis of the ideas. There are many strategies for implementation of cooperative groups, and the books by Johnson and Johnson detail the components and strengths of those. Our experiences in Earth systems education have tested various cooperative learning methods and settings. The form of cooperative learning I use most often is the "jigsaw" (Johnson and Johnson, 1975/1994). This has worked well in our teacher education programs (e.g. Mayer, Fortner and Hoyt, 1995), where teachers have a stake in learning about and using the technique. Briefly, the class is divided into groups of six students or fewer, based on some characteristic that gives them something in common as a basis for discussion. These are the Base Groups. To reinforce their common characteristics, they select a group name. This identity will shape their activities within the jigsaw, as they will be encouraged to apply new learning in the context of their Base Group's needs.

The new learning comes with the activities of Expert Groups. Members of the Base Groups, after preliminary discussions that establish a common background, are divided into working teams that include one or two members of each Base Group. This new group becomes an Expert Group on one component of the subject matter. Activities of Expert Groups are structured by the teacher to assure that certain objectives are met and each group member contributes to the learning experience. Upon completion of those activities, the Experts reassemble into their original Base groups to teach their peers what they have learned. Each student's responsibility to both groups is clear, a combination of learning and peer teaching for a common specified goal.

Base Groups include students with common characteristic as a basis for applying information (major, career goal, etc).

1 1 1	2 2 2	3 3 3	4 4 4	5 5 5	6 6 6
1 1 1	2 2 2	3 3 3	4 4 4	5 5 5	6 6 6

Expert Groups contain at least one member of each Base Group.

1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3
4 5 6	4 5 6	4 5 6	4 5 6	4 5 6	4 5 6

Experts return to Base Groups to share information for common needs.

1 1 1	2 2 2	3 3 3	4 4 4	5 5 5	6 6 6
1 1 1	2 2 2	3 3 3	4 44	5 5 5	6 6 6

Figure 1. Organization of students in a jigsaw cooperative learning experience. Each number represents one student in a class of 36

4. EXAMPLES OF GROUP PROCESS WITH EFFECTIVE RESULTS

In the work of Earth Systems Education, we have used cooperative learning in a number of ways. Described here are examples of how jigsaw techniques have been used at three levels of learning to help develop global science literacy.

4.1. Undergraduates learning about their professional literature

While undergraduate students are learning the basics of their sciences and how those information components are combined into lessons, I have them examine the literature of the field with their own professional needs in mind (Fortner, 1999). The genres of science literature are many, but as college students, I invite their attention to the primary science reporting, secondary features based on those writings, television treatment of science, and popular writings for practitioners (educators, in this case). The jigsaw process is most effective for such an activity. The purposes of this group process are several:

- Expanding the amount of science materials to be introduced in a short time.
- Providing people with perspectives similar to their own (rather than from the instructor's viewpoint).
- Introducing new professionals to literature they may want to have in their own professional libraries.

The procedure followed is summarized below. This information has been previously reported in the *Journal of College Science Teaching* (Fortner, 1999) and contains Johnson and Johnson's (1999) structural steps for formal cooperative learning: Pre-instructional decisions, Explanation; Monitoring; and Assessment.

> An initial brainstorming session with the full class is used to focus attention on how [the profession] uses its literature. Discussion includes the primary literature of science, interpretive literature for various target groups who need the science information (such as teachers, recreationists, researchers, etc), information produced by special interest groups, environmental news as part of other news coverage, and the like. We attempt to cover as many sources and recipients of environmental information as the students can envision.
>
> In the meantime I collect from colleagues, home, and students at least 5-6 samples of publications that represent each category of literature. Each category will be used in a separate jigsaw, so the categories will need to include as many different publications as there are Expert Groups. For example, a category of "Science Background" might include publications best used by an informed audience. In other words, to get the most from this category of science literature, a reader would have to know some science first. Based on availability such a set of literature could encompass *Science, Bioscience,*