AMER. ZOOL., 30:715–722 (1990)

Science as a Way of Knowing—A Summing Up[1]

JOHN A. MOORE
Department of Biology, University of California, Riverside, California 92521

Never in the history of our nation has the need for a scientifically literate citizenry been greater and never in the history of our nation has the educational establishment so obviously failed to meet that goal. We have been told so often that the lack of education in science and technology is compromising our future that a frequent reaction is a yawned "so what else is new?" But the problem is not to be yawned away and it is critical that it be solved.

The most recent flurry of bad news has Lauro F. Cavazos, the Secretary of Education, saying, "As a nation we should be appalled, *appalled* that we have placed our children in such jeopardy." Further, he reported that one-third of high school juniors cannot write an adequate job application and two-thirds cannot write a good letter. The percentage of 17-year-old students capable of "adept reading" is 46 percent for non-Hispanic whites and about half that for blacks and Latinos. There is an interesting parallel between this racial sequence and the number of hours high school students spend on homework each week. For the San Francisco region the numbers are: non-Hispanic whites, 6.12; blacks, 4.23; Hispanics, 3.98. Asian-American students top all the rest with an average of 7.03 hours. The reverse sequence holds for numbers of hours spent watching television.

David Kearns of Xerox has denounced schools as a failed monopoly that is producing workers with a 50 percent defect rate, and as a result businesses must hire workers who cannot read, write or count and then spend $25 billion a year to train them. This is after the nation spends $353 billion a year on education.

These are the young people who will soon be joining the work force—a work force that will toil in a world becoming ever more complex and technologically sophisticated. Worldwide the future will go to those societies that see to it that their children are well educated in order to compete in the world today and tomorrow. This fact of modern life is hardly news as this quote from Whitehead (1929, pp. 22–23) shows:

> In the conditions of modern life . . . the race which does not value trained intelligence is doomed. Not all your heroism, not all your victories on land or at sea, can move back the finger of fate. To-day we maintain ourselves. To-morrow science will have moved forward yet one more step, and there will be no appeal from the judgment which will then be pronounced on the uneducated.

The ghost of Copernicus would rest fitfully if told that less than two-thirds of a combined sample of United States and British citizens realize that the earth circles the sun, and that less than half of these know that phenomenon takes a year (Durant *et al.*, 1989). And as we move into a future where genetic engineering will call for profound and difficult scientific and ethical decisions, the same study found that less than half of the sample knew that DNA has to do with living things.

Those who lament the bankruptcy of the educational establishment almost always have the nation's competitive position in mind. They are right to be so concerned but equally important is the resulting impoverishment of young minds and hearts. In the world of today and tomorrow, freedom to enjoy and prosper in that world demands ever more meaningful education. Most students leave the classrooms with little understanding of either the nat-

[1] From the Symposium on *Science as a Way of Knowing—Neurobiology and Behavior* organized by Edward S. Hodgson and presented at the Centennial Meeting of the American Society of Zoologists, 27–30 December 1989, at Boston, Massachusetts.

ural or the man-made worlds. Not surprisingly both seem remote, cold, incomprehensible, and often truly threatening. Yet those are the worlds in which they will spin out their lives. Surely a prime purpose of education is to prepare the youth of today to live effectively in the world of tomorrow.

The requirements for effective educational reform are so daunting that the work of no single group can be expected to solve all the problems, yet those who teach biology in the colleges and universities, together with fellow scientists in other fields, must play a critical role in any reform. University scientists rarely think of themselves as responsible either for deficiencies in the educational establishment or for remedies—and this has a great deal to do with why we have a problem. All too often they think their main responsibility is research and the training of professional scientists. General education is of secondary importance at best.

But those who teach biology and the other sciences in the colleges and universities must accept major responsibility both for current inadequacies and for the initiation of sustainable reforms. These scientists are in their key positions because it is they who provide the capstone education for those students who will become the leaders of government, industry, and society in general; they define the fields of learning and make major contributions to new knowledge; they provide the scientific education for those who will teach in the K–12 grades; and they nurture in their laboratories the scientists of tomorrow.

These varying responsibilities are met with varying success. The universities are vigorous in advancing our understanding of the natural world and in the education of those who will become professional scientists. I doubt if anyone will claim, however, that the teachers of science have educated those students who will teach in the K–12 grades sufficiently well to produce a citizenry competent enough in science to carry the human experiment into the distant future.

In fact, the achievement of a broadly based scientific literacy is the *sine qua non* for a sustainable future for humanity and for much of the natural world. That goal will require a total overhaul of the educational establishment in which the teachers of science will play a vital role. Consider some of the major things that must be done, beginning with the desired end and working back through the mechanisms for its accomplishment.

First, there must be a critical mass of citizens who are capable of understanding the scientific and technological phenomena of the world well enough to ensure that human beings will achieve a balance with the natural world. That is, the demands for human life cannot exceed the carrying capacity of the environment. Renewable resources—land, water, and air—cannot be exploited beyond the ability of natural cycles to regenerate them. Non-renewable resources that are destroyed—coal, gas, petroleum—must be used with great prudence and with concern for the generations to come. Non-renewable resources that need not be destroyed—iron, copper, aluminum, and other metals—must be borrowed from the environment and recycled.

Beyond this basic survival information, all citizens should understand the natural world to a degree that will give intellectual and emotional enjoyment. Apart from enriching an individual's life, such understanding would go far in making that individual anxious to preserve the world that sustains all human life.

The gap between this necessary goal and the existing situation is immense and totally unbridgeable given the educational establishment of today. That establishment demands very little exposure to science and almost none to technology. Most students devote less than 5 percent of their schooling to these twin forces that shape our civilization. The needed level of scientific literacy cannot be achieved unless the fraction of time for instruction in science and technology is increased to 20–25 percent.

I am not suggesting that this heady fraction consists of more science of the sort now provided by the schools. If we quadrupled the sort of science most students are forced to endure in the K–12 years, we might well kill the scientific enterprise itself. Little of what we now provide helps people

understand the natural and man-made world they experience, and surely they are not given enough to understand the biological basis of the serious environmental and social problems that beset civilization today. Are students left with useful information about the two areas where biology has made its main contribution to human welfare—medicine and food? The science that is needed must be relevant, concerned with solving problems, and involve the students personally in obtaining information through observations and experiments. Science must be seen as a way of learning and knowing and not as a body of largely unrelated facts. The scientific mode of thought must be compared with other modes and the strengths and limitations of each, as well as the areas of their respective usefulness, must be considered.

The existing educational establishment cannot be called upon to provide the type of education in science just described. The task requires many more science teachers and those science teachers must be educated in new ways. One can imagine the convulsions in the educational establishment should there be an increased emphasis on the sciences and that the number of *science* teachers be greatly increased. In theory there need not be a greater total number of teachers since students need not take more courses—just different courses.

I would argue that the best science teachers should be assigned to the K–6 grades. That is where, today, we stifle the great interest in nature shared by most students and where, with truly gifted science teachers, young children could come to appreciate the natural world and never develop a fear of science as a way to understand that world. These are the years to observe and learn about stars, sun, moon, planets, wind, clouds, mountains, valleys, rocks, fossils, streams, lakes, seas, plants, animals, light bulbs, energy, toasters, wheels, levers, foods, household chemicals and machines, water supplies, fire, heat, and seasons.

The list is "natural history" plus everyday technology. A very large percentage of what is observed and becomes personal knowledge can be gained by direct observations and with the skilled guidance of a teacher with a deep knowledge of science, technology, and children.

Many voices are calling for the science of the middle schools to be human-centered—and especially "me"-centered. This is reasonable, since the interests of this age group are largely self-centered and advantage of this could be taken to emphasize human biology and the technology of the student's immediate environment.

If the sciences did occupy that desired quarter of the K–8 curriculum, then the science of the four high school years could be centered in part on important human problems in which scientific data can play a role in making informed decisions about remedies and solutions. I would argue, also, that the basic problem to be faced is that neither the human experiment nor the natural world can long sustain the current behavior patterns of *Homo sapiens.* Somehow the sapient mode must come to prevail.

The real world with which college and university teachers have to deal, however, finds students coming to us with little understanding of science and, more often than not, with an acquired dread, revulsion, or apathy toward science—states not innate but fostered by the negative experiences with whatever K–12 science they have encountered.

Although I have described the current situations, they are little different from those prevailing in 1982 when the *Science as a Way of Knowing* project was initiated. We were deeply concerned and decided to try an experiment—SAAWOK—to see if that might help.

Since this is our final symposium it is appropriate that a few words be said about the genesis and development of the SAAWOK project. In late 1982 Ingrith Deyrup-Olsen had been asked by the then President of the American Society of Zoologists, Peter Volpe, to become chair of the Society's Education Committee and I was asked to become a regular member. Ingrith and I had worked together since the late 1940s at Barnard College (Columbia University), as well as with the Biological Sciences Curriculum Study. For the latter she had served as the first Supervisor of the so called "Blue

Version" and I of the "Yellow Version." Later we both worked on the Yellow Version.

Our first Education Committee meeting was to be held in late December 1982 in connection with the annual meeting of the Society in Louisville. Ingrith requested that I come prepared to offer suggestions for a vigorous program that the Education Committee could consider.

Oral proposals were made and then incorporated in a memo of January 11, 1983. I argued that educational reform must start with the colleges and universities and that professional biologists were in a key position to undertake remedial actions. Concern was expressed that as teachers "we are overly concerned with giving our students the flavor and substance of exciting discoveries in modern biology while we fail to provide a conceptual framework for the field. We convey more information than understanding."

Our project was to be called *Science as a Way of Knowing.* We proposed to divide the field of biology into six, later seven, major fields and to develop each one in a symposium and film session at the ASZ annual meetings. The symposium papers, on current developments, were to be published together with a substantial essay developing the background of each field. All parts were to be pitched at a level appropriate for the first-year college and university courses in biology and the total package was to be directed to the teachers of such courses—there was no attempt to propose a specific course but, instead, to provide materials that could be used to varying degrees by teachers to develop their own courses.

Everything in that first memo became part of the SAAWOK project except for one thing: we had planned to have "a session (workshop?) to demonstrate practical laboratory exercises." We never were able to include that in the SAAWOK package.

I agreed to guide the project for the first four years: plan the program, arrange the symposia, write the background essay, arrange for publication and distribution of the symposium volumes, and handle the correspondence. It was possible for me to assume this responsibility since, in July 1982, I had reached the statutory age of retirement at the University of California, Riverside, where I was still actively doing research. Little did I know how much work would be involved in this new endeavor. From December 1982 until the present, SAAWOK has been my full-time project. All plans for a retirement that would find me active in field and laboratory work on *Drosophila* had to be postponed.

The spring of 1983 was spent in getting under way. The deadline for submitting a proposal for a symposium for the 1983 Annual ASZ Meeting in Philadelphia had passed but an exception was made and we proposed *Science as a Way of Knowing—I. Evolutionary Biology.* By the summer we had speakers for two sessions. Pete Volpe and Bill Mayer were to speak about general problems of education in an evening session and Marvalee Wake, Steve Gould, and Bruce Levin were asked to divide the field "and discuss current problems in evolutionary biology in relation to the conceptual framework of the field" the following morning.

A major effort was made to elicit the cooperation of other societies, and especially their education committees. We were greatly encouraged when The American Society of Naturalists, The Society for the Study of Evolution, The Biological Sciences Curriculum Study, The American Institute of Biological Sciences, The American Association for the Advancement of Science, The National Association of Biology Teachers, The Society for College Science Teachers, and The Genetics Society of America decided to become cosponsors. There was never any working relation with their education committees but most cosponsors kept their members informed of our activities and of the availability of SAAWOK publications. In later years The Association for Biology Laboratory Education, The American Society of Plant Physiologists, and the University of California at Riverside joined the group of cosponsors.

During the summer of 1983 I prepared an essay, *Science as a Way of Knowing—I. Evolutionary Biology.* According to our plan,

this would eventually be printed by Allen Press in the format of the *American Zoologist,* but a preprint would be made for distribution to those attending the symposium at the annual meeting in December. The essay together with the papers delivered at the symposium was then to appear in the second issue of 1984 of the *American Zoologist.* Nathan Hart took responsibility for arranging a Film Program.

So far so good—except for one important item—we did not have a cent to our name. We would need a large sum to cover page charges in the *American Zoologist.* Our Society covers half of the roughly $100.00 per page but we would be responsible for the other half. And, of course, we planned to have thousands of reprints that could be distributed to any teachers requesting a copy. We even planned to have a copy sent to every member of the Society for the Study of Evolution. In spite of these problems, Ed Cooper, ASZ President for 1983, told us to go ahead in the hopes that we could obtain funds somewhere.

These ambitious plans would require about $20,000. Several tentative attempts to secure a grant failed but on September 12 Ingrith Deyrup-Olsen applied to the Carnegie Corporation of New York for support. On October 20 the secretary of the Carnegie Corporation, Sarah L. Englehardt, advised us that a grant of $18,470 had been awarded for the first SAAWOK experiment. Ingrith and I can still remember our sense of relief and gratitude when we heard that news. If the Carnegie Corporation had not been willing to take a chance, SAAWOK would have died aborning.

So on to Philadelphia. Our remarkable friends at Allen Press were able to print my 68 page essay and have preprints in Philadelphia in time for them to be distributed to those attending the symposium. But the most astonishing thing in the entire SAAWOK project is that for that first symposium we had an audience. Both Ingrith and I would have settled gladly for an audience of about 30, who were in the room either because they were interested or had lost their way. After all we were proposing reform of the first year biology courses given in the colleges and universities. We suspected that the class of professional biologists who were motivated to come to an ASZ annual meeting might not have educational reform high on their list of priorities. Were we wrong! There were about 14 concurrent sessions of symposia and contributed papers at the time of our morning session and the audience for SAAWOK was greater than for all the others combined. To be sure we had three real stars as speakers, but nevertheless we interpreted the response of the ASZ members as indicating a real interest in what SAAWOK was trying to do.

So on we went and the subsequent symposia were *Human Ecology* (Denver—1984), *Genetics* (Baltimore—1985), *Developmental Biology* (Nashville—1986), *Form and Function* (New Orleans—1987), *Cell and Molecular Biology* (San Francisco—1988), and now *Neurobiology and Behavior* (Boston—1989). As originally planned I arranged only the first four symposia. William V. Mayer and Ingrith Deyrup-Olsen organized *Form and Function,* Bruce Alberts *Cell and Molecular Biology,* and E. S. Hodgson *Neurobiology and Behavior.*

We had been heartened by the response to the first symposium, so the number of speakers in subsequent symposia was increased as was the size of my essays and the final publications. For example, there were twelve speakers in the *Genetics* symposium as well as two papers by individuals who did not speak. The published proceedings, only 115 pages for *Evolutionary Biology,* increased to 350 for *Genetics.* The total for the seven publications will be in excess of 2,000 pages (the total for the first six is 1,757 pages).

Gary Anderson joined Nathan Hart for the second symposium and together they planned and presented a Film Program for each succeeding year. These became an increasingly important part of the SAAWOK program.

A word about the participants in the symposia, all of whom gave freely of their time. About 80 individuals spoke or provided manuscripts for the seven symposia. One need only to glance at the authors of the published proceedings in the *American*

Zoologist to realize that an exceptionally distinguished group of professional biologists has been involved—and established the excellence and usefulness of the project. I am sure it has made an enormous impression when it is observed that many of the nation's top laboratory scientists have taken the trouble to be involved in what might be described as "only an educational project." What these scientists had to say was important, of course, but who they were is nearly as important. They have my sincere gratitude—they have really made a difference. As one individual wrote us, "SAAWOK has snared the Biggies." And indeed we did.

After the first symposium it became obvious that the SAAWOK publications were to have an important influence for they could reach teachers and scientists far beyond the audiences at the symposia. The basic vehicle of distribution is the *American Zoologist,* which goes to about 4,500 libraries and individuals worldwide. The Carnegie Corporation grants have allowed us to print 43,000 copies of the first six symposium proceedings, of which 8,625 remain on hand while the rest have been distributed. The proceedings of some symposia are now "out of print" but the Carnegie Corporation has given us supplementary funds to reprint additional copies of each in the hope that all will remain available until about 1995. If we add the number of the *American Zoologist* containing the SAAWOK proceedings, the grand total will be about 100,000. This sum does not include the thousands of reprints obtained and distributed by the speakers in the symposia.

During the first year of the program most of those requesting SAAWOK publications were college and university teachers in the United States and Canada. Subsequently many requests came from university biologists overseas—representing about 63 nations. In fact, during some periods foreign requests equalled domestic requests. During the most recent year the high school teachers have heard about us and they have become the largest group requesting SAAWOK materials. This is partly an artifact because most of the university teachers who earlier requested reprints asked to be placed on the mailing list for future issues and so continue to receive them but are no longer listed with those requesting materials.

In making the initial plans for the distribution of reprints we had assumed that most requests would be for the proceedings of the latest symposium and after a few years there would be almost no requests for the earlier publications. This has not been our experience. Requests continue to come for even the earliest issues. For example in the first five weeks of 1990, 1,248 reprints were requested. Of these 352 (28 percent) were for *VI. Cell and Molecular Biology,* the latest one available. Requests for the first five totalled 896 (72 percent) and ranged from 172 to 181 for each, thus being essentially equal.

Many individuals have been involved in the SAAWOK project. Nathan Hart and Gary Anderson were totally responsible for the Film Program. The first drafts of my Essays were read by Betty C. Moore, her suggestions incorporated, and then the revised draft sent to Ingrith Deyrup-Olsen and to Bill Mayer until his death in June 1989. The drafts then went to Allen Press in early October and they provided preprints in time for the Annual Meetings in late December. The speed, accuracy, and quality of their work was astonishing. And they are such friendly people. Any "proper" printer should, quite routinely, reduce an author to rubble in a brief time. Not those folks in Lawrence, Kansas. They have been essential in making SAAWOK a success.

Milton Fingerman, the Editor of the *American Zoologist,* and Claudia deGruy, the Associate Editor, have worked hard to prepare the manuscripts for publication and to juggle the printing schedule to ensure that the proceedings come out in record time. They were certainly part of the SAAWOK team and wonderful to work with.

Dozens of biologists, both here at the University of California, Riverside and elsewhere, gave freely of their advice and encouragement. Betty Moore, Ingrith Deyrup-Olsen and Bill Mayer were called on most frequently. Every item of the very voluminous SAAWOK correspondence

went to Ingrith in order to prepare the yearly reports for the Carnegie Corporation. Early on in the project it became clear that I could not handle all of the requests for our publications. Joe Crim took over and computerized the entire operation. Finally his computer was "full" and the task was transferred to Mary Adams-Wiley in the ASZ office in Thousand Oaks, California. That office has also handled the business affairs and made arrangements for the annual symposia.

And, of course, SAAWOK was only possible because of the Carnegie Corporation of New York. They supported the project from the start and have provided a total of $396,900. These funds have been used mainly for page charges and printing of reprints of the symposia. The only other expense, and it was relatively minor, was covering the travel and *per diem* expenses of those involved in the symposia. There were no honoraria or use of funds for secretarial help.

Were we a success? Most certainly, if one can judge from the worldwide response from very many individuals. We were, however, only partly successful in terms of our original goals. We were able to emphasize the concepts of biology and work towards reduction in terminology. Concern for scientific procedures is spread throughout the essays and many of the individual papers. We should have dealt more with human problems for which biology may help with solutions. There was much of this in *Human Ecology* but less in the other symposia. Our greatest failure was in not providing SAAWOK-type laboratory exercises. The problem here was person-power. The very few of us who worked on the symposia had no additional time and, unfortunately, we were not able to involve others in what would have been an equally, if not more, demanding task.

And now we come to the end in the last symposium. It has been an intense but most exhilarating experience for those of us closely involved in the project. The transmission of biological knowledge to the next generation is a responsibility that will always be with us and always require attempts to do a better job because biological knowledge, widely understood and acted upon by human beings, is the *sine qua non* for the future of humanity. But now we leave the tasks to others.

REFERENCES

Durant, J. R., G. A. Evans, and G. P. Thomas. 1989. The public understanding of science. Nature 340: 11–14.

Whitehead, A. N. 1929. *The aims of education.* Macmillan, New York.

The six SAAWOK publications preceding this one are as follows.

I. Science as a Way of Knowing—Evolutionary Biology. 1984. American Zoologist 24:419–534.
II. Science as a Way of Knowing—Human Ecology. 1985. American Zoologist 25:375–641.
III. Science as a Way of Knowing—Genetics. 1986. American Zoologist 26:569–918.
IV. Science as a Way of Knowing—Developmental Biology. 1987. American Zoologist 27:411–732.
V. Science as a Way of Knowing—Form and Function. 1988. American Zoologist 28:441–807.
VI. Science as a Way of Knowing—Cell and Molecular Biology. 1989. American Zoologist 29:481–815.

POSTSCRIPT

In the few weeks following the symposium two very important statements about educational reform have been made by the leader of the nation and the leaders of the states. These are but part of a pervasive national concern that currently finds frequent expression in the public media. In his State of the Union Address of January 31, 1990, President Bush said:

"Education is the one investment that means more for our future because it means the most for our children. Real improvements in our schools are not simply a matter of spending more. It is a matter of asking more—expecting more: of our schools, our teachers, of our kids, and our parents and ourselves. That's why tonight I am announcing America's education goals—goals developed with the nation's governors:

"By the year 2000, every child must start school ready to learn.

"The United States must increase the high school graduation rate to no less than 90 percent.

"And we're going to make sure our schools' diplomas mean something: In crit-

ical subjects—at the fourth, eighth and 12th grades—we must assess our students' performance.

"By the year 2000, U.S. students must be first in the world in math and science achievement.

"Every American adult must be a skilled literate worker and citizen.

"Every school must offer the kind of disciplined environment that makes it possible for our kids to learn—and every school must be drug free.

"Ambitious aims? Of course. Easy to do? Far from it. But the future's at stake. This nation will not accept anything less than excellence in education." (Text as released by the White House.)

—That from the one who aspires to be remembered as The Education President. Two weeks later the governors of the 50 states released almost the same statement except that they specified those critical subjects for which students would be held accountable: English, mathematics, science, history, and geography.

One hardly knows how to respond when our leaders make such pronouncements and fail to offer any solutions. They said all the right things and dealt with problems that, most surely, are the most critical facing the nation. Nevertheless it is not acceptable to list those problems and then demand their solution with a "let's wave a magic wand" approach. One can only conclude that either the nation's leaders were making political statements or that they are woefully ill-informed. Neither alternative suggests the level of leadership needed to solve the fundamental problem of educational reform.

Consider for a moment what would be required to insure that "By the year 2000, U.S. students must be first in the world in math and science achievement." Presently we are not even in the top group that includes the industrialized nations. The stated goal would require a drastic overhaul of how we teach science, math, and technology; an estimated quarter of the K–12 curriculum would have to be devoted to these subjects; that would require a vast increase in the number of highly educated science teachers; those teachers would have to come from the pool that includes the top quartile of university students; those students would have to be convinced that a career in precollege education would be attractive and rewarding; and, a key to it all, the colleges and universities would have to revamp their programs in the sciences to provide a meaningful and practical education for the prospective K–12 science teachers. And we will have to stop treating students as though education is something *we* can give to *them*. Even the most gifted teachers can do no more than facilitate the personal efforts that a student must make to become educated.

All this would require a fundamental change in how society educates its young and how the young respond to education. The educational system and the society that produce students who test so poorly when compared with those of other nations cannot give the results the president and the governors desire. Even if we could begin right now to initiate the reforms and changes that are necessary to achieve the desired goals, universal scientific literacy could not be attained by the year 2000.

Nevertheless we must start and matters could be made somewhat better by the year 2000. If by the year 2025, the nation could have 25 percent of its citizens in general and 50 percent of our leaders in Washington scientifically literate, it would have achieved an astonishing success—one never before encountered in the history of nations.