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**교육의 역할**  
**The Role of Education**

**Dr. James A. Liggett**

Emeritus Professor, Cornell University



# **Water Environment for the 21st Century: The Role of Education**

James A. Liggett

Emeritus Professor, School of Civil and Environmental  
Engineering

Cornell University, Ithaca, New York

The pretentious title to this paper may indicate that I will lay out an educational program that will remain valid for many years to come. In fact the title simply takes advantage of the fact that a change in millennia is due in slightly more than three years. Long term curricula design is difficult since educational programs are, or at least should be, dynamic, changing continually. And even at present we have serious problems in designing curricula that will serve our students over a career of 40 to 50 years.

Designing educational curricula is an exercise in prediction, specifically prediction on two fronts: We need to know (1) the problems in the future that will be faced by our students and (2) the available technology to solve those problems. To compound the difficulty is the fact that many of the problems, or their solutions, are as effected as much by politics as by physics, biology, and chemistry. As engineers we are not particularly adept at predicting technological and physical changes, but much less so at predicting political changes.

## **THE FUNDAMENTALS**

One point on which almost all agree is that education in water resources, or any engineering subject, should be firmly based on fundamental science, those laws

of science that do not change with time and apply to engineering problems and solutions. Combined with continuing education after the university experience, such a curriculum should, at least in principle, serve the lifetime of an engineer. An education in water resources needs one of three scientific bases for an anchor. These are physics (primary fluid mechanics), chemistry, or biology. In a modern world fundamental physics may not be enough; the student may also need a thorough background in chemistry and biology as well as in such “side issues” as numerical analysis. At the very least we must give our students a thorough background in the scientific method. We must teach our students to be skeptics, to understand that the latest pronouncement on global climate change or an exciting new technology needs to be investigated critically, that scientists (and the press that reports their activities) are as fallible as any of the rest of us.

Aside from the technical education, one needs to live a fulfilling life and serve as an informed citizen in a democracy, so that a grounding in the social sciences, history, arts and economics is important. Indeed, the societal aspects of water resource projects are as important as the technical aspects and requires these other subjects. Just as man cannot live by bread alone, the engineer cannot function by technological knowledge alone.

All of the preceding means that a good education consists of broad knowledge of physics, chemistry, biology plus deeper knowledge in one of these subjects, and an adequate background in the arts, social sciences, economics and history currently packed into a four year curriculum! We are all going to have to tape record our lectures and play them to the class on fast forward just to get the information in. Is a longer period of study (five years?) the answer? I think not. The traditional four years is adequate to provide a basic education provided that the students come to the university prepared for university level courses. For many, however, specialization at the graduate level is highly desirable. Thus, I do not propose a radical change in the existing educational pattern. Instead, education should be dedicated more strongly to emphasis on fundamental science plus an appreciation on arts, history, and economics.

If this outline sounds very traditional, it is, but difficulties, and difficult choices, abound. In the following paragraphs, I will outline my version of these problems and choices. My opinions stem strongly from my background and

those with other backgrounds will have different opinions that are fully valid.

## **CURRICULA**

The following constitutes a few issues of a modern and lasting engineering curriculum in water resources. It is largely physics based, but some of the aspects are valid for chemistry or biological based studies.

### ***Mathematics***

Mathematics has always had a strong role in engineering studies and will continue that role into the indefinite future. In fact, I believe that it will become increasingly important for all engineers, especially since it impacts so heavily on fluid mechanics, computation, statistical analysis and probability, subjects that are certainly important for water resources. Its relevance to chemistry and biology may seem less, but even in these subjects mathematics is becoming increasingly important.

Unfortunately, the engineering curriculum at most universities in the United States (and in other countries of which I have knowledge) do not support rational mathematical education. An old professor expressed it best: "The engineering curriculum is very strange; it spends the first two years teaching mathematics and the last two years teaching how to keep from using it."

That statement expresses two problems: (1) Students often learn something of advanced mathematics but fail to gain a working knowledge or "feel" for elementary concepts. As a consequence they cannot effectively use the advanced mathematics and fail to understand the elementary concepts that form the basis for such subjects as fluid mechanics. (2) Most of the engineering courses avoid expressing problems and solutions in mathematical terms, using instead "shortcuts" and "intuition." These courses lead the student to view the mathematics part of the curriculum as just another hurdle that must be jumped on the way to a degree and not a subject important to the profession.

The second point of the last paragraph seems to illustrate a modern phenomenon: Where there is a conflict between ease of use and ease of learning, ease of learning wins. That conflict was pointed out to me recently by Professor David Caughey in regard to the common hand-held calculator. In years past one could buy two types of calculators, the straightforward algebraic calculator used by nearly everyone today and the RPN calculator that stores a four-high stack of numbers and where the numbers are entered before any operations keys were pushed. The algebraic calculator is easier learn to use, but the RPN calculator, once learned, is much more adept at performing chain calculations. To my knowledge only one manufacturer sells RPN calculators, and only at the upper end (i.e., expensive range); one cannot buy a simple and inexpensive RPN calculator. In general computer software follows the same pattern; in order to sell, make it easy to learn at the expense of easy to use.

I've tried, largely in vain I fear, to convince my students that time spent learning mathematics that is really learning the basics of calculus pays generous dividends in learning, understanding, and computing in engineering courses. Further, it is often the key to continuing education and makes the otherwise difficult engineering relatively simple. We do not do a good job of teaching mathematics and an even poorer job of using it simplify concepts. Certainly, most engineering curricula do spend two years learning how to avoid mathematics.

I predict that engineering will become even more mathematical in the future. Consider engineering design. It has been one of the least mathematical subjects and the refuge for those who are creative but not necessarily analytically proficient. The computer has changed design techniques for the aerospace industry and soon will change them for other branches of engineering. In fact the computer can do a great deal of design more economically, faster, and more precisely than trained engineers. To be sure, some aspects such as aesthetics are not computable and will remain in the province of the engineer (or artist or architect), but even in that regard, the computer can present choices and the costs for those choices. No aspect of engineering or water resources, even some political considerations, is safe from mathematical analysis. Mathematical knowledge appears to be a prerequisite to avoid obsolescence. It is especially necessary to read and understand much of the scientific and engineering

literature.

Of course, mathematics untempered by experience and judgement, especially mathematical design, is an accident waiting to happen. Those who designed the failed Tacoma Narrows Bridge did not make a mistake in their calculations; they only failed to ask the right questions. Mathematical analysis is like a reluctant witness in court it answers all questions truthfully, but provides no information that is not sought directly. Failure to ask the right questions can be disastrous. And, of course, no analysis is better than the data that go into it.

Experience and judgement cannot really be taught in a university. There is an old saying that “Good judgement comes from experience; unfortunately, experience comes from bad judgement.”

### *Fluid mechanics*

Water resources is fluid mechanics. Fluid mechanics is fundamental to anything that happens with water, including the chemical and biological aspects. It is fundamental to water supply, to flood control, to groundwater, and to water quality; it is fundamental to weather and climate phenomena. It contains a broad aspect of traditional (i.e., non-nuclear, non-relativity) physics, thus providing a background in what is known and what is not and how to discern the difference. Thus, this subject should be the basis for an educational curriculum in matters of water resources.

Fluid mechanics opens the door to hydrology, oceanography, meteorology, geology (especially groundwater), and transport phenomena. It is not only fundamental to much computation in water resources, it forms a basis for developing intuition and judgement. But, like mathematics, it is a two-edged sword; if one does not ask the relevant questions, it will not give the relevant answers. Of the three linchpins of water resources (physics, chemistry, biology), fluid mechanics, as part of physics, is the most important.

### *Computation*

The greatest change in engineering in my career has been the advances in

computation. It has changed the way we teach in that when I was a student, most of the time was spent learning how to compute with no electronic aids. Now much of that time can be devoted to a fundamental subject whereby the students learns, for example, fluid mechanics and not the tedious process of finding the flow in all branches of a pipe network. Not only can we compute such problems more easily, we can compute much more complex and significant problems, and the answers are presented in an understandable form with plots and graphs.

As far as computation has progressed in the last forty years, we have yet to take full advantage of the computer, especially in our universities. Only in the last decade has engineering software become easy to use in the sense that it is available to those without some computer training, to those who do not write computer programs. The modern advances in computing lead to two dilemmas:

(1) A money saving device in engineering offices is to use technician or young engineering labor together with design and analysis software, but giving engineering software to the young, inexperienced engineer for design purposes might be like asking the graduate of a driver training course to race in the French Gran Prix. Like a high-powered automobile, that software enables the engineer to perform tasks that are extremely dangerous for the inexperienced. With proper supervision and checking, such an operation is satisfactory, but the key is the supervision and checking.

(2) From the point of view of an educator, what should be taught in computation has become an enigma. Fifteen years ago, it was clear. The engineering student should learn a programming language and numerical methods. The combination of those subjects was the key to productivity and continuing accessibility to engineering software. Now programs are common that require little computer experience and no knowledge of numerical methods. In fact, the student is unlikely to develop numerical methods better than those in some standard software such as Mathematica, Matlab, and Mathcad. Such nonspecific software is being used as the basis for sophisticated calculation just as Fortran was used for programming 40 years ago. Although all of us learned to program in Fortran, none of us at the time learned the basics of developing language compilers. Should, then, we teach our students the basics

of the numerical methods that go into this generation of software? I don't know! My intuition says "yes", the engineers of the future need to know what they are doing at this fundamental level. My reason says that it is for most of our students a piece of knowledge that they will not use and can better be replaced in a crowded curriculum by other subjects.

That dilemma faced Professor Caughey and I as we wrote our fluid mechanics book that is to be sold on a CD ROM. Should we make computation so easy that the students do not have to learn some of the fundamentals of fluid mechanics in order to work problems? Some may say that is precisely what we have done, although I hope it is not the case. We ultimately decided to include a great deal of software that can solve most of the problems because (1) a relief from the drudgery of computation means that the students can spend more time learning fundamentals of fluid mechanics and in gaining intuition about phenomena by changing parameters, (2) we hoped to make the book a handbook that would help the practicing engineer, and (3) any computer based book that does not contain such programs will soon be obsolete. Whether or not we made the right decision, the folding of easy-to-use software in textbooks appears to be the wave of the future. We will not be able to withhold these tools from university students just as we have not been able to withhold calculators from elementary students learning arithmetic.

### *Ecology and environment*

Engineers of my generation were concerned with only one question when faced with a decision on a water resource project: Is it economical? Even the economical analysis was distorted to count all possible benefits but few of the damages, especially damages to the environment, that a project might cause. Such reasoning led to the "big dam" era in the United States and many other countries. Although that era is over in the US (the last big dam is Glen Canyon, completed in 1966, and now acknowledged by some of its former supporters as a mistake), it still flourishes in many countries.

Water resource projects must now pass a gauntlet of enquiries, including comprehensive environmental impact statements. Engineers, as planners, obviously need an appreciation for the environmental consequences of their

works.

Unfortunately, the word “environmentalist” is often used in a negative context. It calls up the image of placard waving marchers opposing every conceivable project, of self-proclaimed protectors of nature who have little knowledge of ecology, and those who would leave undisturbed the habitats of all animal and insect life in the effort to preserve the diversity of species. Even in the university, so-called environmental studies are likely to be shallow with little hard scientific content. But if the engineer sees the environmental movement as one of excesses, his own profession bears much of the responsibility since it ignored environmental considerations for so long. The answer is, of course, that the engineer must be sufficiently informed to answer in a rational manner the concerns of the environmentalists, to support their legitimate objections and rationally refute their foibles. In fact the engineer should be a leader in environmental considerations, but up to the present has not taken that role. Given that water resources is central to the environment, water resource planners and designers cannot be taken seriously unless they become a strong factor in the environmental discussions.

### *General*

The curricular pattern laid out here has as its basis a strong foundation in mathematics, science, and fluid mechanics plus a background in arts, history, economics, and ecology. In a typical four year study program, the breadth of the program leaves only a little time to specialize in hydraulic engineering, chemistry, biology, hydrology, meteorology, or other aspects of water resources. Some such specialization is possible at the undergraduate level, but undergraduate studies will continue to provide a general education with real specialization occurring only in masters and doctoral studies.

The education of the water resources professional is only one aspect of education. In democratic societies the education of the general public is, at least, of equal importance. My point here is that the same principles hold: a public uneducated in basic science, or at least without knowledge of the scientific method, cannot make rational political decisions. It is the responsibility of the water resources personnel to keep the public informed

about any project. Such information includes the economics, environmental consequences, the choices that must be made (including doing nothing), and available alternatives. Usually an informed public will support a well-conceived, rational project if they understand it. Such support may be necessary to overcome the inevitable opposition of special interests who have an economic stake in some alternative projects or decisions.

In fact the most important role of education for the water environment of the 21st century is the education of the general public. Our citizens must know the difference between astronomy and astrology. When more people believe in UFOs than in evolution, we have a problem.

## **ISSUES**

In water resources and general environmental issues, the focus of public discussion is often off target on what is and is not an important issue. Political decisions are important in all countries, and in some countries the politics overwhelm and preempt any possible technological judgment made by qualified engineers. Indeed, that is a common thread among so-called “developing countries” that are actually sinking lower into poverty with their standard of living not keeping pace with the rest of the world and often not improving at all. Technological based solutions to their problems remain useless until more basic problems, political and social, are understood and faced.

Thus, I want to list below a couple of issues that promise to be major ones for the general environmental and economic health of any region, and in particular with respect to water resources. Some such issues are difficult for many areas to deal with due to entrenched political stands, religious beliefs, established economic interests, and political demagoguery.

### ***Population***

In many parts of the world population issues remain among the most

controversial. In the United States they are seldom faced directly and only surface occasionally at the national level in the guise of immigration policy or locally with regard to such items as school financing and transportation and, of course, regionally with regard to water resource projects. In water resources, population is obviously a key parameter that must govern the conception and design of each project, and it is the primary issue that impacts on the economics of projects. It is treated as a parameter that forecasts demand. In fact water resource engineers are fortunate in a sense that in most areas water is available at a price. If all else fails, we can recycle wastewater or put in desalinization plants; the price may be higher than the public can afford or is willing to pay, it may be environmentally destructive, but water is available somewhere.

Other disciplines are not so fortunate. The agricultural and mineral resource of the earth are finite. The consequences of human population crowding out the flora and fauna in some areas are apparent. Air and water pollution have markedly decreased the quality of life and health in many cities of the earth and are becoming pervasive on a regional or even country wide level.

In fact, it is difficult to think of any large scale problem that is not caused or exacerbated by over population.

An example of a badly focused public debate is now occurring near where I now live. The city of Phoenix, Arizona, has been declared as one of only two cities in the US where the three canonical measurements of air quality carbon monoxide, particulates and ozone have all reached a serious level. The other city is Los Angeles. The possible remedy, according to some, is to build public transportation, supposedly so that the automobile contribution to the pollution will decrease. Yet even the supporters of the transportation system admit to a decrease in air pollution of only about two percent. With Phoenix growing at a rate of, perhaps, ten percent per year, that two percent decrease cannot even be measured and will be overcome during the construction of any transportation system.

The problems of Phoenix, and of Los Angeles, could not exist without enormous water resource projects. In both cases the population is partially sustained from diversion of massive amounts of water from the Colorado River.

In the case of Phoenix, the city sits in an arid area, previously obtaining water from the Salt River and from groundwater, but when these supplies could not sustain the population, a systems of overland canals were built to bring water five hundred kilometers from the Colorado River. When water no longer became a limiting factor on population, the consequences of unlimited growth appeared in the environmental degradation of the area. Thus, while the discussion is currently focused on transportation, water resources would be more to the point. The unintended consequence of the Central Arizona Project (the interbasin transfer from the Colorado River) is a decline of water quality in the Colorado River, but even more importantly it has lead to serious misuse of land and agricultural resources, of destruction of wilderness area and animal habitat, of general aesthetics, and has had negative consequences in human health. Are these costs some that should have been considered by the water resources planner? Perhaps even with such environmental costs, the project is economically justifiable it has led to substantial economic growth but consideration of all costs is only prudent.

Obviously, if such areas are to grow, they must have water. But given that there is a finite limit to their size, do we limit that size by rational means, or do we let nature impose its own limits. At least we should be rational enough to have an informed discussion on this matter instead of allowing it to drift along while debating such items as transportation that, while important, can never be a cure and only serves to temporarily distract from the primary problem.

Water supply is not the only water resources issue that has a large effect on population. As more and more people move into the flood plains near rivers, they must be protected by dams and levees. Those dams and levees have their own serious environmental consequences in the destruction of habitat, the flooding of agricultural land and, often, the degradation of water quality. They can and do protect from almost all floods. Most of us must admit, however, that sooner or later a major event will occur that will overwhelm flood control works and cause property destruction, if not loss of life, that may be greater than if the project did not exist.

Population is, of course, the primary obstacle facing the developing world. In any country, if the rate of population increases more rapidly than the gross

national product (i.e., a real estimation of economical growth and not the inflated figures often touted by politicians), the people must become poorer. In the long run we have a simple choice in all countries: limit population or watch the quality of life degrade.

### *Climate change*

None of the invited lectures listed world climate change as a subject, even though it is a hotly debated topic. The impact of climate change on water resources is obvious. Perhaps less obvious is working this subject into a talk on education. But it is a topic that fits well with education and, especially, the choices that an environmentally aware engineer must make. I can think of no other subject that is more confusing, with scientists making dire predictions about global warming and the

almost daily presentation of "facts" that tend to support one viewpoint or another. It rivals the onslaught of information about health and the toxicity of this chemical or that, or the benefits of taking one vitamin or another. At least health relates to individual behavior and lifestyle while decisions regarding human effects on the environment and environmental effects on humans must, for the most part, be collective.

The claims and counter claims can be confusing, as illustrated by the individual who recently circulated a petition asking the government to ban or severely limit the chemical di-hydrogen monoxide. That chemical, he claimed, leads to many deaths each year through accidental inhalation. It is terribly corrosive, limiting the useful life of automobiles and most other machinery. It is a major factor in excessive sweating and vomiting. In its gaseous state it causes severe burns. It is found in most cancers. It is the primary factor in acid rain. It contributes significantly to the erosion of topsoil. It has found its way into most foods that are consumed by humans. Of the first 50 people he asked to sign the petition, 43 did so and only one realized that this dangerous chemical is water.

With regard to climate change, most of us agree that the climate is changing. The disagreement lies in (1) the rapidity of change, (2) the direction of change, (3) the consequences of change, and (4) human's ability to influence the change for better or worse. If one reads the popular press, the answers seem to

be (1) the change is rapid, affecting all of us in our lifetimes, (2) the direction is toward global warming, (3) sea level rise will inundate all communities on coastlines and inland areas will become deserts, and (4) all we have to do to stop these terrible consequences is decrease the amount of carbon dioxide that we admit to the atmosphere through the burning of fossil fuels. Indeed, those were the ideas expressed by the vice-president of the United States in his book *The Earth in Balance*. He states flatly that almost all reputable scientists agree with these conclusions. Perhaps such agreement is his definition of a "reputable scientist."

I don't pretend to be an expert on global climate change, but I find the data unconvincing. No doubt that greenhouse gases have increased dramatically, but that alone does not mean that the earth is warming. The interaction of the atmosphere with the oceans and with plant life is simply too complex and too little understood to draw definite conclusions from the increase in greenhouse gases. As to the direction of change, I have data from the northeast United States that indicate, with a certainty of about 500 to one, that the region is in a long term cooling trend. Of course, those data are neither the quantity nor quality to be dependable, even on a regional basis, but similar data have appeared in the press in support of global warming.

Moreover, the consequences of global warming might not be as severe as we are led to believe. The US Department of Agriculture conducted a study that indicated a few degrees change would have little effect in the US. The Russians seem to view any warming with eager anticipation of a longer growing season in much of Siberia. They may be correct that any temperature change would be felt primarily by the agricultural community in the length of the growing season. Warming could have a positive effect on world food production. Certainly, it would be much better than its opposite, whereby in a length of time only a bit longer than recorded history has buried much of the northern hemisphere in ice.

William A. Nierenberg, formerly Director of the Scripps Institute of Oceanography and former Vice Chancellor for Marine Studies at the University of California-San Diego, makes the point that significant effects of global warming are 100 to 150 years in the future and that those effects are on the

order of one degree Celsius. Further, he states that no benefit is to be derived from immediate action. He urges awaiting developments, especially new technologies in energy development and new data on climate change before the world's resources are spent on a threat that may not exist. He urges that economic resources not be spent in an attempt to fight global warming a move that could cause more harm than good and states, "For now, there are no firm answers, and we should not act as if there are. Let the scientists do their work in the neutral climate of scholarly inquiry ..."

However, the proponents for action argue that global climate change is more than a curiosity where we can sit back and await developments. Many engineering projects, certainly water resources projects, are heavily dependent on climate statistics. All of our plans carry assumptions, explicit or implicit, about climate statistics; they are of great economic consequence. More immediate is the question of whether we expend thousands of millions of dollars in an attempt to control climate, and, if the answer is yes, where do we spend those monies. Such decisions are in the public domain and can be made only by an informed electorate. Of course, the public cannot understand all of the scientific jargon and the equations that enter into global climate models, but those who choose to educate themselves can be rational and lead to informed opinion that carries the day.

We won't always be right, but without education we surely won't make the correct decisions.

### ***Research and Graduate Studies***

As an academic, one might suspect that I am strongly supportive of research into anything that has to do with water resources. Indeed I am! The answers to some of the question that have been posed above can come only with continued research.

Some of the best research has and is being done by students and faculty in our universities. The proliferation of graduate studies in the last 50 years has led most universities and colleges that offer an engineering curriculum to establish post-graduate programs that offer masters and doctorate degrees, the research

degrees that require a student to advance knowledge in order to receive a diploma. The graduates of these programs populate the faculties at most universities so that nearly all engineering instructors now have a doctorate.

Herein lies a classic case of population explosion. Most doctoral students have been well indoctrinated in the research function. Upon graduation they want to have their own research programs, complete with external funding and students. If during a lifetime a faculty member turns out only 10 doctoral students most have more that means the population of doctorates increases by an order of magnitude in a single generation. But how many do we need? Are all of these students getting a first class graduate education? Are they all doing meaningful research?

The answer to these questions seem obvious. We have in only one or two generations reached the saturation point. Too many graduate programs exist in engineering. In any product, when the number becomes great, the value decreases. (And so it is even with our undergraduates, who are unable to command good salaries commensurate with some other professions.) That is the way it is with doctorates; their value, and the value of the research they do, has shown a marked decline simply due to their numbers. One only has to pick up any one of several scholarly journals in education and examine the papers, written mostly by academics. How many such papers have an impact on anything; in fact, how many are even read by more than a very few engineers?

The move in the mid century to increase the number of doctorates and the research was greatly needed and has succeeded admirably. But we now have enough! We now need quality, not quantity.

Most universities in the United States have no business offering graduate programs in engineering and science. There are literally hundreds of such institutions, yet when one begins to list high quality programs, they usually stop at around ten or, possibly, 20. Perhaps if the US had only about two dozen universities that offered doctorates in engineering, the process could reach a steady state with high quality programs leading to meaningful research. Perhaps it would also be a solution to the glut of publications. As a former editor of the ASCE Journal of Hydraulic Engineering, I was amazed that in no area does

research ever cease. Some subjects are simply beaten to death by continued research, which leads to increasingly small advances. When we have an infinite number of Ph.Ds each making infinitesimal advances, the result is more likely to be zero than a finite number.

## **CONCLUSION**

The decline of quality in university education in the US and in some other countries is well known. Especially in the arts and social sciences, the universities have lowered standards while the students have received better marks. Engineering has not been immune to this trend. In fact we require much less of our undergraduates than was the case 30 years ago. In spite of that trend, however, we are still graduating well trained, if not well educated, engineers.

We should be graduating fewer but better educated engineers. Many of our graduates are competing with machines, or will be shortly. They will lose in such a competition lose salary and lifetime earning potential. A thorough, rigorous, fundamental education one that teaches critical analysis in addition to problem solving will serve our students throughout their careers. And it will serve our profession.

Graduate programs and graduate research need an overhaul so that the number of doctorates emerging from such programs is no more than is useful to society, primarily our educational and research institutions.

In short, the sort of education that I propose for the twenty-first century is not fundamentally different from the education of the twentieth century, but it needs modernization and an elimination of the excesses. It needs a return to rigor in the context of the computer age.