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The Relationship
ENGINEERING
to Engineering Practice
EDUCATION

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Table of Contents

SECTION 1

Environmental Engineering Workforce and Markets: Today and Tomorrow

A World Without Barriers or Boundaries

J.C. Goldman

This conference has an appropriate theme concerning relevance between environmental engineering and the practice. As we begin to think about closing out this century and moving to the next, it is time to be retrospective about where we have been, where we are going, and some of the global issues.

I would like to talk more from the perspective of the individual environmental engineer — the employee. As I began to look at the theme, I asked myself what are the impacts on the environmental engineering professional? What changes have we seen occur in the past few years and what changes will occur? We have heard a lot about the "X Generation", which is now coming out of school. They have a different perspective on things. One of the perspectives, and I am sure those of you that have been teaching them know, is that they want quick answers. They want to solve a problem precisely and very rapidly. And that is an interesting perspective to bring to a public works project, where there are 96 proposed solutions and only two or three that are actually implementable.

And where are they going to lead us in the next decade? We can look back and we can look at what my generation did, the "Y or (Why?) Generation" is all I can call us. We questioned everything in the late sixties and seventies. I think Vietnam caused us to do a lot of that. But we questioned things and we caused a lot of changes, because we asked: Why should we do it the same way? In the nineties, I think we have still not recovered from the "Me Generation" of the eighties that has wreaked havoc on Corporate America with buyouts, acquisitions and the demise of many corporations. Who would have ever thought that International Harvester, the number one farm implement supplier, would not exist today as a company? We have seen that throughout industry after industry. Companies that were leaders no longer exist. They have been merged into other companies or have broken up into components. For example, American Can is now a financial services company and not a papermill company.

So looking forward, what is this new generation going to do for us? Well, I think they are going to be faced with a lot of challenges that will need to be resolved. The challenges are significant. In the developing world alone, there are one billion people without safe drinking water and 1.7 billion people without any sanitation facilities. Eighty percent of the disease in the developing world today is the result of poor water supply. Ten million people annually die as a result of waterborne disease in the developing world.

Economic stress has resulted in significant urbanization pressures. In thirty years, nine out of the ten largest cities in this world will be in the third world. Only Tokyo will remain in the top ten. In Africa alone, we have seen the urbanized population in the last twenty years go from 83 million to 206 million. The population growth of the African urban areas has been two and half times that of the continent.

The challenge is significant, and the challenges will be felt here and in the rest of the developed world. In the U.S., we just passed, the Safe Drinking Water Act Amendment, which includes $7.5 billion for water system improvements to the State Revolving Loan Program. We estimate that at least $40 billion, and most people say that is a low estimate, will be required to clean up sewer overflow problems in the U.S. In Europe, a number of the economies that are still feeling recessions are under significant pressures environmentally to upgrade their wastewater systems to meet the new EC standards — particularly in France, Italy and Spain. So the challenges are there. The question is: How will we in the environmental engineering workforce and those that are entering the workforce in the coming years face those challenges and deal with them?

We are graduating today the most academically prepared group of young engineers in the history of this profession. They have stronger SATs as they enter, and stronger academic credentials and learning academic know-how when they leave the programs than any of us had thought possible. And they are computer literate, which puts a lot of us to shame. But, they are going to enter a business world that very rapidly will challenge them to find new skills, and challenge them to learn to work in teams. In the classroom, it is individual performance. In the classroom we take examinations, we turn in homework problems, we turn in whatever is necessary and we are graded. And, the reward is immediate. You go into the real world, success is in teams, not breaking a project or a problem up into individual components for individuals to solve, but in "group think". Solutions are the result of consensus. Solutions result from many, and often various, inputs.

They are also going to face a world where security is not there — job security, security of know-how. Things change. The new vocabulary of the nineties is re-engineering, rightsizing, outsourcing, privatization, quality, virtual teams, open communications and, for those of us who deal in the public works world, freedom of information. Everything is an open book. If you say it, it may be in the paper tomorrow morning. If you write it down, it surely will.

This is the world that they are entering and they are going to have to learn to deal with problems that are not clear. We give a student a problem to solve. They are then expected to take that problem definition and create a logical and precise solution. But how do you solve water supply problems in a community that has just voted down six rate increases in a row? The need is there, but the solution is not obvious. That is the challenge that they will face. Oftentimes the first question is: What are we trying to do? Why are we here? The problem is not clear. The need is clear, but the problem and its solutions are certainly not clear.

The successful environmental engineer, as we enter the next century, will first be a team player that has to learn to work in an open environment where ideas are created and shared, often by a committee. Usually the accepted concept is the one that everybody at the table says: "I can live with that: Not that it's mine, or I agree that it's the best, but I can live with it." That is the answer that has to be found.

We in the environmental engineering profession have abdicated much of our leadership opportunities. We have not had a lot of input into policy. We have not had a lot of input into direction. That has got to change. We must become more active in the political arena. We must become more active in our communities. We have the know-how. We have the ability to provide that input to help craft the solutions and map the directions to solve these problems.

In addition, the successful environmental engineer must become a strong listener. Proactive listening — finding out what the real problems are, what the agendas are, what can the community live with, and understanding the social, political and economic impacts of the potential solutions. And put it in relevant terms. Recently, I was in a workshop discussing a technical solution, and there was significant discussion about how we could not afford to spend $10 million for this particular solution because it was just too much money. Then, we started putting it back into perspective and its real impact. The $10 million capital expenditure, and the $2 million annual operating cost increase that this particular ozone system would have put on the water system would raise the rate payer's cost by 1%. Yes, it was a lot of money, but to the rate payer, the voter, it was a 1% impact. As it turned out, an improvement in the bond rate, by refinancing the bonds, would more than offset the cost. We must start thinking in terms of those numbers. It is disheartening when you are sitting in a room and ask: "Well, what is the water rate or the sewer rate that the community has now?" Even among us, less than a third can raise their hand and say: "We know what it is." In the U.S. today, the average city water rate is $14 a month. The average wastewater rate is $17 a month. Thirty-one dollars a month! That is $3 a month less than the average cable TV service charge in this country, yet it is too high. We have to understand the relationship of the economics in which we work and the economics of the communities in which we deal.

Those of us who deal with some industrial entities are already facing significant "go/no-go" decisions on siting new facilities or expanding capacity, because of the environmental cost. In Maine, the pulp and paper industry has been hit severely by the environmental impacts of water pollution, air pollution and the management of forestry lands, or ecosystem management. The successful environmental engineer must learn to live with rapidly changing rules, where all decisions are questioned, and where the input comes from many different sources. We are a knowledge-based industry, and we have to use that knowledge to find solutions. And notice I said "knowledge", not technology. Technology is one element of our knowledge that we use. It is an important element, but it is only one element of the whole knowledge base. In fact, our entire business is based on knowledge. It is a human business. And it either succeeds or not, by the quality of the people and their ability to use their knowledge to create solutions that satisfy our customers, whether we are in industry, consulting, or the government sector. We ultimately have a customer, a stakeholder, that we have to provide value to by using our knowledge to demonstrate the appropriateness of a solution, how to deal within the associated economic structure, and how to avoid pricing a product, say, newsprint, out of a competitive range if the mill is sited or developed at this location. These are the types of things that will separate the successful environmental engineer from the technician as we go forward over the next decade.

As we begin to think about the impacts that you in the academic community will have on the new environmental engineer, we need to think about how you will cause them to be a more open individual, looking for knowledge growth opportunities, learning how to deal with sales and marketing. Ultimately, any project is paid for by somebody. And we environmental engineers do not pay the bills. We have to learn how to work in a community for somebody else on those facilities. We have to learn to communicate — communicate in the language of the customer.

The title of this topic is: "A world without barriers or boundaries." Actually, it should have been: "A world without protection." Because those boundaries have protected us from being questioned by our customers, from being questioned by a lot of the no-growth community, by a lot of the community that feels that we are leading in the wrong direction. We have been protected by the political community. We have been protected by the industrial groups of the chairman and board of directors. Those barriers are now gone. We are on-line. Project after project is on-line. Take the Tolt River Reservoir Water Plant in Seattle, for instance. That project is on-line today for anyone who wants to see what is going on by going to the Internet and examine the project status. Weekly, in Engineering News Record, you will find a new construction project, whether it be a highway project or a new viaduct project or a water plant in Tampa, Florida, that it is physically on-line in the Internet. Sometimes it is protected by what information you can access, but in many cases, under the Freedom of Information Act, the information is open to whoever wants to check into it and question what is happening with their taxpayer dollars.

We have to be solution driven. We must define or at least put limits around the problems and find solutions that bring value to the community. Foremost, we must be leaders. We work in groups. We live with stakeholders that oftentimes are not technically prepared, oftentimes have a single agenda. They must be brought into these decisions and made part of the solution. Ultimately that is our responsibility as the expert in the field, who as individuals can cause the various attitudes to be brought to a solution.

So we face a turning point in the road. There are three kinds of people in the world. There are those who go out and change the way things are being done, there are those who watch the way things change, and then there are those who don't know what hit them. And we are at the point to decide which we will be.

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Environmental Engineering Workforce and Business Challenges for the Year 2000 and Beyond

Philip G. Hall

It always takes me a little by surprise when someone asks me to forecast business and career trends. While I recognize that because CH2M Hill is of one of the world's largest design, construction and operations companies, we have a unique vantage point on the changes taking place in the field of environmental engineering, but it still takes some getting used to the thought of being viewed as visionary. In many ways we think of ourselves as a bunch of guys from Oregon, not as a $1 billion, 7500 employee firm operating on 6 continents.

I know that whatever our future is, it will build off our past record of accomplishment and public service. The work we do is *vital* to a strong economy and will remain so.

I say that not just as a professional who is duty-bound to promote our industry, but as one who has experienced first-hand the affects of life without basic sanitation infrastructure. In my earliest days as an environmental engineer, I served as a Peace Corps volunteer in rural Ecuador. My assignment there included helping to build a public water system for the small village of Matus. Having the opportunity not only to make a lasting contribution to the village, but to witness first hand the positive changes it brought to the people there, was a life-changing experience for me.

Thinking back, I can recall how the people of Matus were accustomed to frequent bouts of intestinal disorders. Having experienced many such bouts with amoebic dissentery myself, I can honestly say that I have a real "gut" feel for just how vital our work can be to the economy of communities, states and nations. Poor public health has a debilitating effect on an economy. Simply stated, when you don't feel well, you don't work very efficiently.

So, the *need* for what we do is and will remain vital and viable. But our role in *delivering* our services will change a lot!

When asked to forecast the future of our business and profession, I feel like I'm living up to Laurence J. Peters' definition of an economist. Peters describes an economist as "an expert who will know tomorrow why the things he predicted yesterday didn't happen today." In other words, give me another four years to prepare for this presentation, and I'll have a real good picture of what our profession looks like in the next century. For those of you who just can't wait that long, let me give you my best "educated" guess as to where things may be headed in the next 1,000 days and beyond.

We do face some incredible changes in the days ahead that will cause us to completely change our ideas about — *Who* we are...*What* we do...*Where* we do business...and *How* we go about serving our clients.

Who We Are

I noted with some interest that AAEE observed its 40th anniversary last year. As you may know, our company is observing its 50th anniversary this year and for roughly half of that period of time, we have carved out a business identity for ourselves as one of the nation's leading environmental engineering firms. I'm sure that many of you work for organizations that share similar backgrounds.

For both CH2M Hill and AAEE, "environmental engineering" became a differentiating descriptor that conveyed the essence of our organizations to our clients and colleagues. And while the environmental engineering moniker is still applicable in most cases, it no longer adequately describes the full scope of CH2M Hill's services, nor what our clients expect of us these days.

In the formative days of our profession, clients most often called on our services for technological solutions to reduce pollution and manage resources as mandated by federal and state environmental laws. While compliance with environmental regulations continues to prod many of our clients to initiate environmental projects of one sort or another, often these days economic factors drive decisions about managing environmental issues and resources.

As the Progressive Foundation's Center for Innovation and the Environment has noted, "Squeezing still more environmental benefits from aging treatment plants and factories that already have significantly reduced their emissions, or from public lands and water reserved for species conservation, will require much higher costs to produce much smaller results than the earlier efforts."

The bottom line for most of our clients these days is that spending on environmental engineering and management has itself become a bottom-line business issue. In the past 25 years, the quintessential environmental project funding question has shifted from "What will it cost us to comply?" to "What return can we expect on our investment?"

To me, this represents *bona fide* evidence that sustainable development (first introduced for me at the Earth Summit in 1993 in Rio de Janeiro) is not just a far-flung theory, but a practical business notion. Now that the calculus for environmental management has come to include not just one, but both sides of the balance sheet (not just a liability, but an asset that can generate a return) business and industry are entering the era of sustainable development.

As the International Institute for Sustainable Development suggests, "The sustainable business has interdependent economic, environmental and social objectives, and understands that long-term viability depends on integrating all three objectives in decision-making. Rather than regarding social and environmental objectives as costs, a sustainable enterprise seeks opportunities for profit in achieving these goals."

For business purposes, the Institute defines sustainable development as, "Adopting business strategies and activities that meet the needs of the enterprise and its stakeholders today while protecting, sustaining and enhancing the human and natural resources that will be needed in the future."

What does this tell us about who we are as professionals? What it suggests to me is that the environmental engineering discipline that we all have in common may be due for an evolutionary change. While the discipline has made a profound impact on our world for a quarter century now, and will continue to do so, more than likely it will represent only one component of a larger suite of sustainable engineering, construction, and management disciplines that are needed in the next century.

Along with this expanded sustainable development role for environmental engineers, I expect to see an expanded role for our profession in the policy arena. As environmental policy moves away from the first generation "command and control" regulatory framework to a less confrontational, collaborative approach that addresses environmental and sustainable development issues, the door will be open to us to become a part of the policy development process.

As a profession, I'm sorry to say we really have abdicated our policy role to the lawyers and to politicians. There are 535 members of Congress of whom less than 10 are degreed engineers. Yet we have knowledge and insights the public needs and has a right to expect!

What We Do

Whether or not sustainable development turns out to be the *modus operandi* for managing the environment in the next century, clearly we are headed toward a new era in environmental policy here in this country.

As William Ruckelshaus described it in a recent address to Princeton University (April 22, 1993), "Command and control is inherently expensive and inherently inefficient, because every firm has to move in lock-step, directed by a bureaucracy; because there's no real incentive for technological advance; and because most of what you're doing is collecting pollution at the end of a pipe and then you have to find somewhere to put it...

"If the cost of waste disposal...becomes a significant fraction of the cost of making something, it will tend to influence industrial processes, to make them less polluting, just as the cost of a raw material will influence how much of it will be used in a product."

Or as my colleague Ralph Peterson told the ASCE Water and Environment Conference earlier this summer, "The important point for us is that we will have to think of our future role as environmental professionals in terms of a new relationship to the *processes* of economic development (manufacturing, transportation, building, resource management, and the like), not primarily in the "cleanup" mode. The emergence of clean technologies to bring about waste-minimization, pollution prevention and sustainable development is a technological trend that I suspect will both *improve* and *complicate* our professional lives."

With the exception of combined sewer overflow systems, the days of mammoth cleanup technology projects in this country are on the decline. What lies ahead for our profession are the waste minimization and environmental management issues that build pollution prevention into plant processes and community infrastructure.

Where We Do Business

Perhaps many of you are tired of hearing that we now find ourselves operating in a global marketplace. It may be of little consolation, but I also suspect that countless blacksmiths tired of hearing that the "iron horse" and "horseless carriage" would revolutionize the world in their lifetimes. By that I do not mean to trivialize the impact of global market forces. Quite the contrary, I mean to point out that the global marketplace we operate in today is as much a reality with profound impacts at the turn of this century as the automobile was at the turn of the last century.

Let me share some revealing statistics with you that lead me to say that. According to a recent study conducted by *The Economist* (Oct. 1, 1994):

- Developing countries will grow by nearly 5 percent a year, compared with a rate of 2.7 percent in the rich industrial world.
- At current growth rates, the industrial economies will account for less than half of world output by the end of the decade.
- Within a generation China will overtake America as the world's biggest economy.
- By the year 2020 as many as nine of the top 15 economies will be from today's third world.
- The third world's share of exports of manufacturers jumped from 5 percent in 1970 to 22 percent in 1993.
- In the midst of all this macro-economic change, we add population on this planet equal to a new Tokyo every 40 days. China alone adds another Australia every year.

What should we make of all this?

Well to me, the population figures are depressing, but they do represent market opportunities to be sure.

When you combine the forecast economic growth with the life and death environmental needs faced by much of the developing world, you have the basic ingredients for a "green rush" (as contrasted with a "gold rush") of epic proportions.

While major investment in environmental infrastructure may be on the decline here in the U.S., the market for environmental technology outside our borders stands ready to erupt. When you realize that over the next 25 years, more than 3 billion people in Asia, Latin America and Eastern Europe will join the ranks of citizens of relatively wealthy nations. And when you consider that a large portion of that population currently contends with substandard water and sanitation conditions, you have a recipe ripe for market boom, political upheaval or both.

One personal example I can share is in Russia. Their radioactive waste problems have received worldwide publicity. Yet on a recent visit there, their Minister of Environment told me that Russia's greatest threat to public health is unsafe potable water supply.

For the moment, you and I, along with our other U.S. environmental engineering and technology colleagues, enjoy a distinct advantage over many of our foreign competitors. What the emphasis on environmental protection in this country has bought us is a quarter century headstart in dealing with cleanup issues. The living laboratory we've worked in these past 25 years provides us a very tangible skill set that represents a highly valued and tradable commodity in the world environmental marketplace.

That's the good news.

I wouldn't be giving you a complete picture of the foreign environmental marketplace without a look from the "glass is half empty" side of the ledger, however. From that perspective, I see two probable threats that will make it tougher on all of us to compete for jobs both here and abroad.

The approaches to problem solving that our 25 year portfolio of environmental engineering practice provides us may turn out to be a liability.

In some respects, our business and profession stands where the American automobile industry stood in the late 1960s. Like the auto industry of the 60s, our track record for accomplishment is the envy of the world. As reported by the Progressive Foundation;

- "Health benefits brought by cleaner air have far exceeded the cost of air pollution controls.
- Industry has substantially reduced its use of toxic chemicals and ozone-depleting chlorofluorocarbons."

And as Gregg Easterbrook pointed out in his book *A Moment on the Earth;*

- "Miles of fishable and swimmable rivers in the U.S. have more than doubled, with nearly 60 percent of U.S. rivers now in compliance with Clean Water Act standards."

But also, like the U.S. auto industry of the 60s, the marketplace model in which we are schooled will not likely be the model applied in the developing world. While there surely will be some regulatory driven cleanup in developing countries, the far more likely model will be an emphasis on sustainable development, and economic-driven solutions that combine economic growth with environmental objectives.

Foreign competitors are increasingly being drawn to the U.S. environmental market.

While it is true that the developing world represents the fastest growing market for environmental technology and services, the U.S. market remains the world's largest. According to *Environmental Business International, Inc.*, over the past 25 years, expenditures on all types of environmental activities in the U.S. have grown from 0.7% of U.S. GNP to almost 2-1/2% of GNP today. In 1995, this represented about $150 billion of an estimated $400 billion in worldwide environmental expenditures. So the U.S. is today about 40% of the world market.

Again, like the U.S. auto market of the late 1960s, the U.S. market for environmental or sustainable services will attract foreign competition trained in solving both economic and environmental challenges, and accustomed to methods of project delivery only recently coming into vogue in the U.S.

In addition to intensifying the competition for environmental projects in an already crowded field, foreign competitors entering the U.S. environmental market will likely change the playing field, or at least the rules of the game. Many of our French and British competitors, for example, compete using their balance sheet strength as a competitive weapon.

How We Do Business

How we do business with clients is almost certain to change with new players in the game. Specifically, if as commonly forecast, the future model for project financing and development in the U.S. becomes some form of privatization or alternative, non-traditional modes of project delivery (such as turnkey or build-own-operate) our foreign counterparts can be counted on to bring their own competitive edge into play, namely a track record with these alternative approaches to project delivery.

As projects like the Tolt River water treatment plant in Seattle demonstrate that design-build-operate is a viable approach to project development, and as federal, state and municipal governments grow even more strapped for cash to fund major construction projects, it seems inevitable that privatization or unconventional approaches to project delivery will begin to take hold here in the U.S.

Preparing for the Future

How should we prepare ourselves and future professionals for these changes? I leave that to the professional educators among you to decide how all this translates into curriculum changes and academic course work. My one suggestion is that whatever curriculum we develop must provide both a solid core technical foundation and the flexibility to accommodate the sea change we are rushing toward, mainly via a commitment to lifelong learning.

Industry and the marketplace demands new skills in language, the ability to work in cross-cultural settings, and a broader understanding of all the elements required to take a project from concept to successful operation.

If I may use an analogy, our professional education and training system must be as rigorous, hard-hitting and focused as a football training camp in order for us to compete effectively in the next century. At the same time, our training must be limber, pliable and sustaining enough to prepare us just in case the game we're preparing for turns out not to be football, but fùtbol!

Besides a cross-training approach that furnishes both solid technical background and the versatility to adapt to changing playing conditions, our formal education systems must also instill a proactive professional sensibility. While we must be prepared to adjust to a changing set of rules, we must do it in a proactive, anticipatory fashion, not by taking a wait-and-see approach.

Like a blacksmith turned auto mechanic, we must be willing to transform ourselves and adapt to new working conditions. It's not enough to be an effective navigator — we must become pathfinders who are willing to set a new course when change demands it.

As futurist John Schaar describes it, "The future is not a result of choices among alternative paths offered by the present, but a place that is created—created first in the mind and will, created next in activity. The future is not some place we are going to, but one we are creating. The paths are not to be found, but made, and the activity of making them, changes both the maker and the destination."

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Collaborative Development of New Design Tools to Improve Productivity, Innovation, and Learning

Darryl W. Hertz

Abstract

Design of economically and environmentally sustainable processes depends on the designer's easy access to relevant and usable technology information and guidance. Merely increasing the engineer's access to growing amounts of unsorted and poorly organized information often proves frustrating and unusable. Because design engineers often work under tight schedules and with limited information access — learning, innovation, and productivity are less than they could be. In the area of environmentally driven process improvements, this becomes especially important. Improving design productivity while also improving understanding of relevant engineering principles continues to be a challenge. One solution is more intuitively developed engineering design tools. Industry-University-Government partnerships appear to be uniquely positioned to develop such new tools because of the combined breadth of design and operations expertise, understanding of the underlying chemistry and engineering principles, and the financial resources to make it happen. One such partnership has been active in this effort. More are needed. The result of such collaborative efforts will be industrial designers using the same design tools to more easily design production and manufacturing facilities as would senior engineering students to learn engineering and design principles.

Long-term technology innovation depends on well-informed and uniformly-informed design engineers. This is true in large as well as small organizations. Until now, quick access to usable technology information, case studies, and lessons learned from within the same industries and organizations was difficult or impossible. The Clean Process Advisory System (CPAS™) is being developed under collaborative agreements by three major consortia to improve access to examples of new clean technologies, lessons learned, and waste reduction improvements from across *all* industries.

Background

Achieving a sustainable result while improving manufacturing processes means that the customers' most important needs have to be satisfied as well as the organization's needs. For those developing and licensing production or manufacturing technology, this means customers should be offered the best technology and performance at the lowest possible life-cycle cost. It also means consideration should be given regarding how to achieve maximum waste reduction in a very competitive market without compromising existing high levels of safety, reliability, operability, and maintainability.

Achieving such performance will enable industry to continue to control overall operating costs as environmental restrictions continue to tighten. The result is staying economically healthy in today's global economy. To achieve better environmental performance as well as production performance will require more effective communication of lessons learned and capabilities of new and emerging technologies between groups within industrial organizations, between industries, between universities and industry, and even between universities.

Designers' lack of knowledge of emerging, applicable technology information or process alternatives has been cited as a significant barrier to pollution prevention (U.S. Congress, 1994, 231). Additional value is usually derived from the consistent use of information, not merely the possession of it. Moreover, little value-added results from conversion of printed information into electronic information. Better organization for the intended user group is needed.

Much of technology information today is either widely scattered, not in an accessible location or format, or has been produced for other uses. This prevents faster and less expensive implementation of new technologies in industry. Moreover, it significantly reduces the transfer of otherwise applicable technology information between industries. One could reasonably postulate that the same applies to the engineering undergraduate and graduate student. Therefore, improved means of conveying useful information on an as-needed basis for use by those making design decisions or trying to gain a true understanding of the underlying principles of the technology will help make long-term pollution prevention goals more easily achievable.

The answer is not just more printed or electronic information to try to sift through. More organized information is needed — configured the way the intended users prefer it. Information so "high-graded" and prepared for the intended users should be differentiated as "Design Tools" as they assist the designer in making more informed decisions via review and consideration of more relevant options. They should not be confused with "knowledge-based" systems that claim to be able to make some of the decisions for the designer. Many in industry feel such computer decision making is unwise and much prefer design tools that *only* assist, advise, or inform the designer.

Rationales for Development of New Design Tools

While it is true that significant opportunities to reduce waste generation still exist via process modifications (U.S. Congress 1994, 231), achieving such reductions requires far more information and an understanding of the process chemistry and details of the operating characteristics of the facility and the technologies contained within it. While many have written about the important distinctions between data, information, and knowledge, it is knowledge that allows the owner to predict outcomes, synthesize new variations of the information or process, and to make decisions about potential applications of the knowledge (Bohn 1994, 61-62). In the case of design engineers, knowledge of the process and applicable technologies contained within it is naturally of high importance to industry for financial reasons. It is also of high importance to university engineering faculty for educational reasons.

Requirements for sustainable technology and operations changes are significantly more complex than end-of-pipe solutions. It should be thought of as a quantum leap in the amount of information and understanding required when compared to end-of-pipe solutions. This fact has often been misunderstood by those not experienced in process and product design. Not only is more information necessary for sustainable process changes, but a far broader range of available information is needed. This must include an understanding of the interactions of pollutants and contaminants with product streams, catalysts, and equipment. It should also include an understanding of the fate and transport of pollutants and contaminants, if discharged to the environment. Also needed are lessons learned from others that have accomplished waste reduction design improvements.

Imparting comprehensive technology-related knowledge effectively to others in this electronic information age should be best done using design tools or decision-support tools. Expert design of the user interfaces based on the users' preferred use and format of the information can effectively convert scattered and poorly organized information into design guidance. This expert design of decision support tools should best be done by multi-disciplinary development teams. Industry-University-Government partnerships appear to be uniquely positioned to develop such new tools because of the combined breadth of design and operations expertise, understanding of the underlying chemistry and engineering principles, and the financial resources to make it happen. The question is, "Who is personally motivated sufficiently within each organization to champion such collaborative design tool development?"

Design tools should assist or advise the designer *only*. The designer should always be the decision maker as he or she is responsible for the correct, safe, cost-effective operation of that design. They should be developed to function as though a group of seasoned experts were standing behind the designer or student and offering additional information and guidance when options are being considered. If this is emphasized, faster integration of new waste reduction technology, techniques, and their underlying principles will result at the lowest possible life-cycle cost. Improved design tools will allow the designer and/or engineering student to close the loop on chemical production and manufacturing with no hazardous or toxic effluents to the environment. They will also allow consideration of economically sustainable improvements in technology performance and engineering design, not just short-term solutions based on a limited availability of information or guidance. Such tools should help bridge the gap of new college engineering graduates and their more experienced counterparts in industry.

The long-term objectives for development of usable design tools should emphasize environmentally sustainable technology improvements over end-of-pipe control solutions. This is not to say that end-of-pipe solutions should not be considered. Such solutions should always be considered, but only after viable source reduction and recycling solutions have been exhausted. In order to allow the designer to easily consider such a wide array of potential solutions to each design issue, new assisting or advising tools must be developed. Moreover, because designers rarely have extra time on their hands, such tools would be best developed so incorporation into existing design tools is possible. The resulting design tools should be easier and quicker to use than the tools in use now. This will improve the effective transfer of process and operations improvements throughout an organization. If development purposely is directed toward all potential users in numerous industries, inter-industry technology transfer will result. Obviously, this will only involve non-proprietary information.

Even with additional understanding achieved, economically-viable, long-term improvements require a multidisciplinary team effort. Such teams should consider including process design, research and development, operations, maintenance, detail engineering, marketing, equipment engineering (vendors), environmental engineers, consultants when expertise is not available in-house, and management.

Benefits of Better Design Guidance and Decision Support Tools

Design tool development and their widespread use will make long-term environmental improvements more achievable for technology, processes and procedures. These results happen to be the goals of most organizations involved in production or manufacturing. Some of them are listed below:

- Inherently Safer Operations
- Higher Reliability
- Lower Capital Cost
- Reduced Air Emissions
- Higher Conversions
- Better Catalyst Selectivity
- Lower Temperature
- Lower Pressure
- Greater Feedstock Flexibility
- Lower Energy Requirements
- More Compact Designs
- More Process Water Reuse
- Reduced Wastewater Toxicity and
- Greater on-line Factor
- Reduced Contaminants Within Process
- Reduced Startup and Shutdown Effluents
- Reduced Maintenance Costs
- Greater Ease of Operations
- Simpler Designs
- Reduced Vent Gas Flaring

Listing them as goals is one thing, achieving most of them is quite another. Improving the time needed and long-term expenses of achieving them are the goals of better design tool development. Make no mistake, these goals have been achieved by many, and for some, they are consistently achieved now within process improvement programs. Better design tools will make them easier, less costly in the long run, and more consistent.

Collaborative Development Efforts

Development of new design tools for pollution prevention has been ongoing for some time throughout industry, academia, and government. These separate initiatives are focused on the development of more effective design tools to help make more environmentally sustainable designs possible. However, they have not been adequately coordinated to reduce duplicate effort and to make possible a "system" of tools that have some defined and functional continuity. One such national collaborative effort working toward that continuity is CPAS.

CPAS is a computer-based pollution prevention process and product design system. It is composed of a number of separate, compatible, and interactive programs containing design information regarding new and existing clean process and product technology, technology modeling tools, and other design guidance.

The current CPAS development effort involves numerous collaborative partners including industry consortia such as the Center for Waste Reduction Technologies (CWRT), the National Center for Clean Industrial and Treatment Technologies, and the National Center for Manufacturing Sciences (NCMS). The collaborative effort also involves private companies, universities, federal and state agencies, and national labs. What is most important, CPAS development involves and depends on a small number of individuals who are committed personally to the effort. This also means that a number of companies and organizations support those individuals so that such development can be accomplished. Today, there are about 29 design tools being developed within CPAS. Twelve design tools have working development versions completed with beta testing to begin this summer. There are many more design tool development efforts that are consistent with the goals of CPAS, but have not yet joined the CPAS development team.

Many in industry who are engaged in the effort to economically reduce waste generation in-process will agree that one of the most significant technical barriers to further reduction is the lack of knowledge of available alternatives for designers to consider at the decision point (Cheremisinoff 1989). Some have also indicated that an additional barrier to further pollution prevention is that applicable technologies are not yet developed to the point of commercialization (U.S. Congress 1994, 245).

While these are only a few of the many restrictions to further waste reductions (Freeman 1995), consider these issues from the perspective of the design engineer. Who can tell the difference if little usable information is available to them? What current information sources advise the designer about technology application from other industries? From a stream-by-stream evaluation of process effluents from many different industries, what are the differences in these streams, other than the contaminants? Further, technology applied routinely in one industry may be considered innovative or emerging in another. It is this cross-industry technology transfer of information and lessons learned that the CPAS development team is attempting to fill.

Conclusions

Transfer of technology information and lessons learned can be improved via better design tools. More consistently informed designers means more economically sustainable processes and products. Collaborative development of new pollution prevention design tools offers better opportunities for industry overall. The CPAS development team invites your organization's involvement as well as your personal involvement and commitment, without which it will be less than it should be.

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Environmental Market Trends and Research Needs

Richard K. Miller

We have identified what we see as the top ten major trends in the environmental marketplace. Figure 4-1 reflects these trends.

Figure 4-1
Ten Major Trends in the Environmental Marketplace

1. Shift from regulatory market drivers to economic market drivers
2. Due diligence and legal liability become predominant market drivers
3. Residential, Commercial, and Municipal sectors grow as industrial and federal sectors plateau
4. Pollution prevention market growth peaks
5. Operations and maintenance becomes major area of opportunity
6. Emphasis on economically sustainable solutions
7. 'Era of water' begins
8. ISO 14000 emerges as a market driver
9. Boom in the international marketplace
10. A new way of doing business in the engineering marketplace

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The first trend that we observed is a shift from the regulatory driven market to an economically driven marketplace in the environmental field. Several things are fueling this — not only a decrease in the emphasis on new regulations and enforcement, but some factors that are making the economic aspects more important. The cost of water is increasing. It is forecasted that the price of water will increase by 100%, or double, in the next five years. Whether or not that happens is questionable. I recall seeing that same forecast five years ago. But, at some point since, water is underpriced in the United States, the price of water is going to dramatically increase, economically fueling that market. The value of material reuse is increasing. The economics of recycling has shifted, where recycling is now a profitable business. In the remediation field, it's becoming recognized that remediation not only has a value in complying with laws, but that there is a value associated with the real estate of these waste and contaminated sites. Rather than Superfund being the buzzword in the remediation field, brownfield cleanups is the new current area of emphasis. According to EPA, there are something like 30,000 potential sites in the United States that are not realizing their economic potential because of contamination, and there is a $10 billion potential remediation market associated with cleaning up these sites and developing them, not because of regulations, but because of basic economics. To initiate this, some fifteen cities in the United States each received $200,000 of EPA grants to develop these brownfield sites.

A second trend that we see is due diligence, and legal liabilities have taken the place of regulatory market drivers, and are now the predominant drivers. Corporations are realizing that we are spending a few million dollars and they may be confronted with a multimillion dollar litigation by EPA. Liabilities are much more important. These are fueling reactions or opportunities in the consulting marketplace. We did a survey of environmental firms to ascertain their areas of activity, and we found that while certain activities of environmental consultants are on the decline, the performance of risk assessments and environmental site assessments is on the increase. These are both $100 million or multi-$100 million fields (Figure 4-2).

A third trend that we see is that as industrial and Federal market sectors in environmental spending have plateaued, residential, commercial and municipal market sectors are growing. In the residential and commercial sectors, we are talking about things like indoor air quality. The sales of bottled water still have double-digit market growth rates, even though the environmental field is tapering off. It seems that people have this new impression that the government is not going to protect our environment quite to the extent that it appeared a few years ago, so we have to take it into our own homes to protect our environment. One way to do this is to install water purification filters or purchase bottled water. Another residential activity is taking legal actions to protect the "not in my backyard" concept against environmental hazards from moving in. The environmental market community is recognizing that there are opportunities in smaller businesses like dry cleaners, hotels, reuse of water in laundries, and some of these other areas that are beyond the smokestack era of mentality in environmental protection. We are discovering the economic viability of these opportunities.

Figure 4-2
Expenditures for Liability-Driven Environmental Assessments

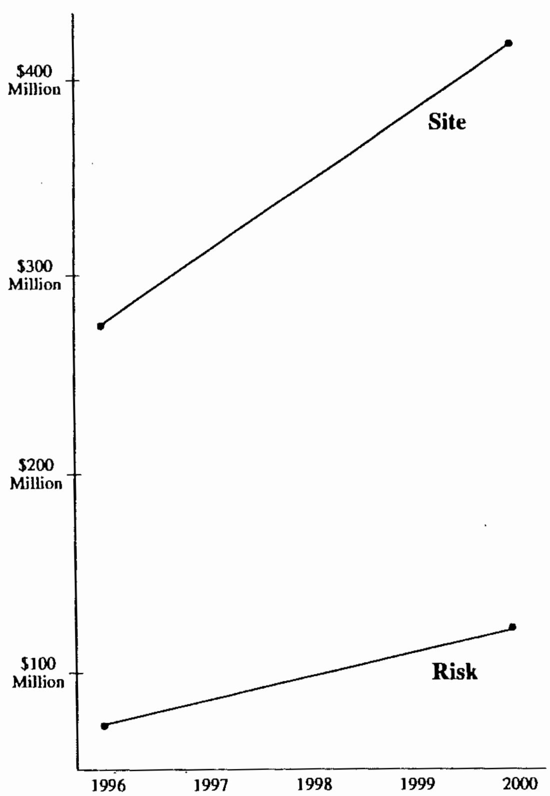
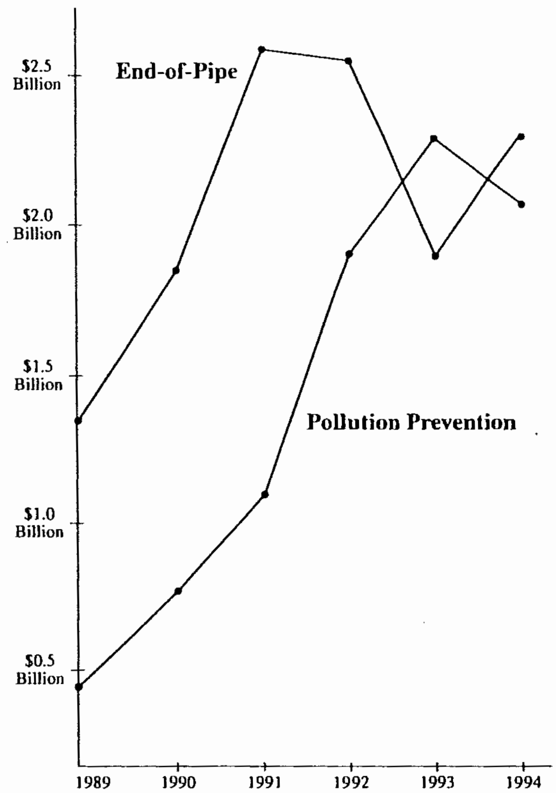


Figure 4-3
Manufacturing Air Pollution Control Capital Expenditures

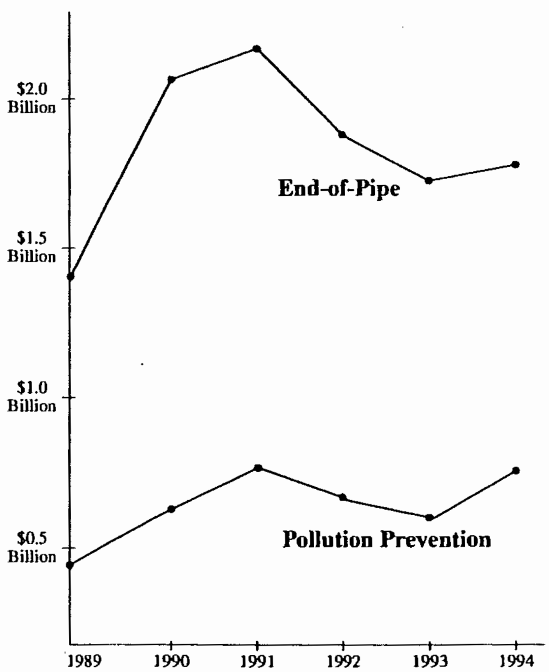


Source: U.S. DOC

A fourth trend that we are seeing is that the pollution prevention market growth is peaking (Figures 4-3, 4-4, 4-5, and 4-6). This is not to imply at all that pollution prevention is not the engineering wave of the future, but one hears or reads that there is a "new approach" called *pollution prevention*. The related legislation is the Pollution Prevention Act in 1990. That's six years ago. 3M's 3-P program is not a new program, it's a very established program, and similarly, N.W. Kellogg's pollution prevention program was publicized in the late eighties or early nineties. What has happened in the marketplace is that, starting with 1989 on up to 1994, based on Department of Commerce data, one can see that pollution prevention expenditures were about a third of that which was sent on end-of-pipe treatment in 1989, but actually in 1993, more money was spent on industrial pollution prevention, air pollution than was spent on end-of-pipe. In the water pollution field, industrial water pollution, there was a general decrease of spending on end-of-pipe solutions while pollution prevention has continued to increase. Translating these numbers to market growth rates, the real growth rate when pollution prevention was a new idea occurred back in 1990 and 1991, when the market grew something like 50-60% per year. These are more established areas now, more established concepts, and the growth rates are diminishing. What this means to researchers and engineers is that the first wave of pollution prevention in industry — the low cost or more evident solutions have already taken place in the chemical, petroleum and other heavy industries — and what lies ahead is a second wave of more complex solutions in those industries. Also, it takes the pollution prevention concept into some of the smaller industries such as hotels, dry cleaners and your food and beverage industry. This brings on new technologies and new challenges.

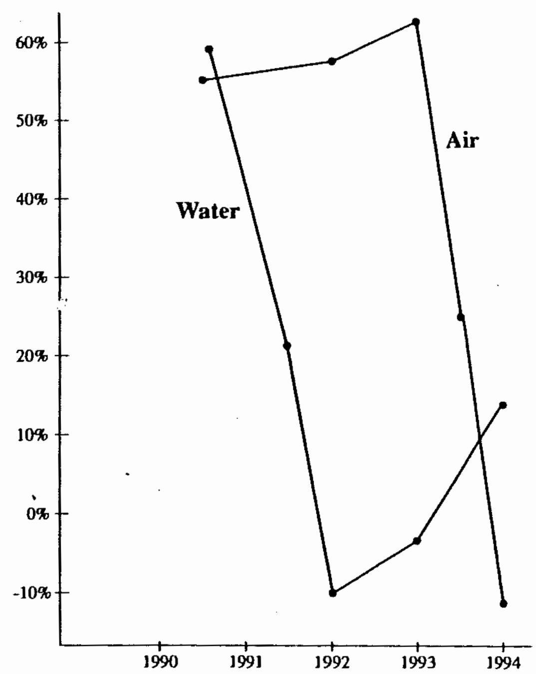
A fifth trend that we have seen is that operations and maintenance of pollution control systems have become a major area of opportunity (Figure 4-7). Looking at the Department of Commerce data breakdown of industrial expenditures for pollution control over the last five years, it is clear that pollution prevention is catching up with end-of-pipe expenditures but, at the same time, operation expenditures have actually dwarfed either of the two. Operating expenditures, which represent at this time something like 71% of all industrial expenditures on pollution abatement, are defined as energy costs to operate these systems, labor costs to operate the systems, material policing expenditures, outside contract work and payments to government for either water, and trash removal (Figure 4-8). This is where the big money is being spent right now and, even though it is not glamorous like pollution prevention, a lot of environmental companies are looking at contract operations for municipal water systems, industrial outsourcing to actually come into an industrial facility and operate their water pollution control system for them. Thus, they can enjoy the profits they receive, or benefit from the savings that they can effect by energy savings, wages savings, or implementing pollution prevention.

Figure 4-4
Industrial Water Pollution Control Capital Expenditures



Source: U.S. DOC

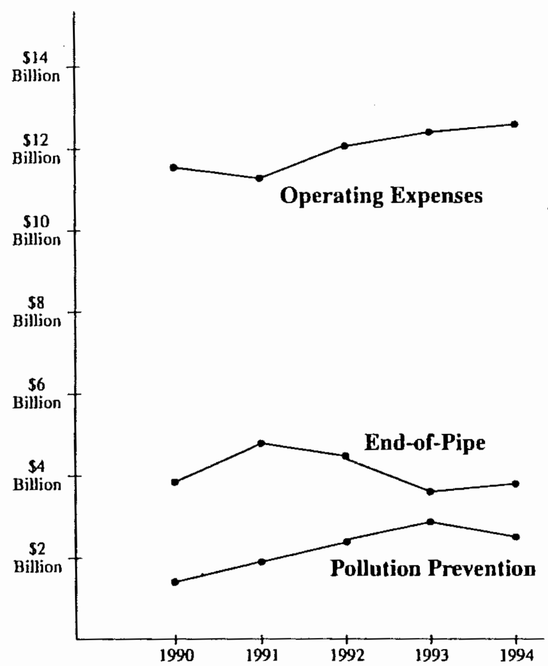
Figure 4-5
Pollution Prevention Market Growth Rate



Source: U.S. DOC

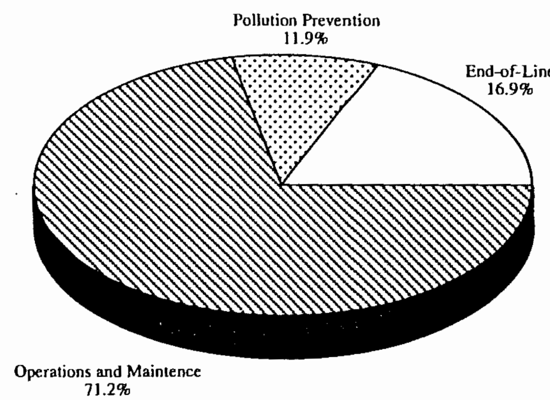
A sixth trend is an emphasis on low-cost solutions. Many have indicated the need and recognition in industry for sustainable economic solutions. And what has brought this about as a reality is the development of some low-cost technologies that have been researched — bioremediation, and now a newer area photoremediation, which is the use of aquatic or land plants to cleanse contaminants. These lower-cost solutions have brought down the cost of pollution control and allow the benefits to exceed costs, making pollution control more economically viable.

Figure 4-6
Manufacturing Expenditures, Air and Water Pollution Control



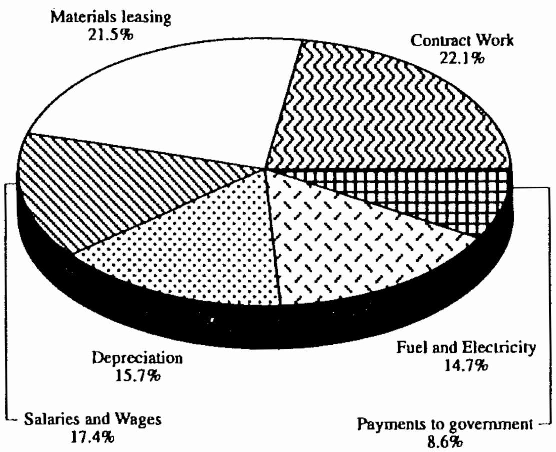
A seventh trend that we are seeing is, as the Environmental Business Journal calls it, the "era of water beginning." This the kind of the main newsletter of the business aspects of the environmental field, and in November, 1994, their headline was "the dawn of the water era begins." The article goes on to say that we've gone through basically two pollution control areas, the first being the smokestack era of the 1970s. Billions of dollars were spent in the pipe controls, and that era tended to fade away. The second area was that of toxic controls, and both pollution prevention, initial remediation of those things that caused that area to somewhat be more under control. Now the main expenditures are seen as being in the water industry. We have gathered from the news that there is something like a dozen municipalities in the United States that will, over the next few years, be spending a billion dollars or more each on their water pollution and water systems — Miami, Las Vegas, Atlanta, Boston, New York. For most of the major cities, expenditures are on the order of a billion dollars per city. One will not find those kind of expenditures, with a few exceptions, in other areas of pollution maintenance.

Figure 4-7
Industrial Expenditures for Pollution Control



The eighth trend that we are seeing is ISO 14000, the International Standards Organization environmental standard, emerging as a market driver. We did a survey on what may happen related to ISO 14000 certification, and our panel of members of the environmental auditing roundtable estimate that this year about thirty companies will initiate certification. And, by the year 2000 or 2001, this will involve roughly a thousand companies a year. This involves a real opportunity for environmental consulting firms to do the environmental auditing and the environmental corrective measures to allow companies to comply with that standard. We found that the average expenditure by company will range from $100,000 to $200,000 for the initial consulting associated with establishing ISO 14000 certification, plus an additional $50,000 to $100,000 a year for the annual consulting audits. Multiply that by

Figure 4-8
Operating Expenditures

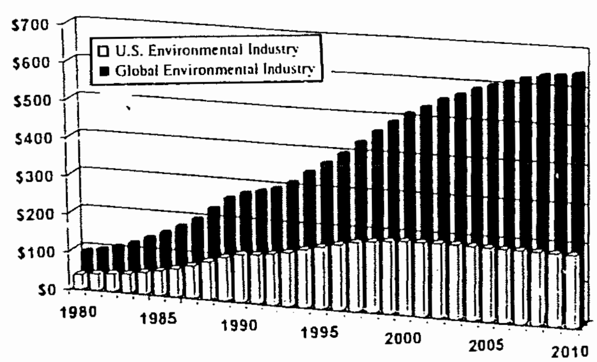


the 3,000 companies that are expected to initiate certification, and it would suggest that about $300 million will be spent in this brand new segment in the next few years.

The ninth trend is a boom in the international marketplace (Figure 4-9). Again, citing some data from Environmental Business Journal, EBJ expects the expenditures on environmental services to plateau in the United States. A lot of this is due to the fact that problems simply have already been solved, and pollution prevention is taking effect. And, around the year 2005, we can expect an actual decrease in expenditures on environmental controls in the United States. At the same time, worldwide expenditures will continue to increase. So this is really where the opportunity is for environmental companies in the United States who look at participating in these foreign projects and looking at exports.

Finally, a tenth trend is that we are seeing a new way of doing business in the environmental and engineering marketplace. Some of the service options are consulting firm partnering or teaming up with the clients to have joint consultant and in-staff house groups attack projects. There is some performance contracting. For example, in the energy conservation field, engineering firms will come in and implement, at their own cost, but at no consultant cost, certain measures. They will share the energy savings as their payment for the project. In the water management chemicals field, the sale of chemicals is being replaced by what are called *delivery services*, where the chemicals will be sold with a service that includes computerized assessment of the use of these chemicals in a total package. In the municipal water field, there are contract operations, where a consulting person will come in and actually manage the municipal facility. Similarly, industrial outsourcing is seeing the same thing happen in the industrial field. A few years ago, design and build became predominant in the design consulting field. Now we are seeing design and build operate, where the engineering firm may actually come in and manage the facility. And finally, we have finance design and build operating, where the engineering firm has to bring a lot more to the table than the previously did. I read where CH2M Hill, for example, has started a financing subsidiary, where they come in (maybe a foreign country) and help develop the financing for a water treatment project. And we are seeing some full privatization where few municipalities in the United States have already actually sold their water treatment facility to a private company, resulting in the private company operating that facility.

Figure 4-9
International Marketplace



The top research needs are based on responses that we received in surveys of environmental equipment manufacturers and environmental consulting firms asking, among other questions, "what are the research needs in a particular sector of the environmental marketplace." I have made ten generalizations on those responses (Table 4-1). Number one, there is a need for a review of or verification of the health effects and regulatory criteria. In areas like ergonomics, indoor air quality and radon, there is

Table 4-1
Ten Areas of Need in Environmental Research

1. Review, better understanding or verification of health effects and regulatory criteria
2. Environmental risk assessment methodologies
3. Better understanding of microorganisms
4. Advance sensors
5. Energy efficiency in pollution control systems
6. Application of industrial engineering in abatement and in the operation of pollution control systems
7. Alternatives to the use of chemicals
8. Advances, especially fouling reduction, in membrane systems
9. Expanded real-world applications of bioremediation
10. Active noise and vibration control applications

simply a feeling among those in the field that there is not substantial scientific basis for the criteria that have been proposed, and there are some research needs there. Environmental risk assessments — where something like $200 million are spent on needs assessments — we find there are not any standardized methodologies. There is not a good understanding of or certainty of cancer or measures of risk, so there is research needed in that regard. A lot of the research needs that we saw identified related to a better understanding of microorganisms — for example, in bioremediation, municipal water filtration, air duct, and microbiotic contamination. There is need in several environmental areas for more advanced sensors, simplified sampling for indoor air quality, sampling for multi-gas and toxigas monitors, faster and more accurate pesticide detection, and other chemical detection in the water quality implementation area. Several of our survey respondents indicated the need for more energy efficient and pollution control systems. Again, as indicated earlier, one of the big areas of expenditures by industry in pollution control, is energy costs. Something like $2 billion per year is spent by industry alone, not counting municipalities, in the operation of their systems. Similarly, another big area of expenditure is on labor associated with the operation of these industrial pollution control systems. Something like a billion and a half dollars a year is spent by industry on labor operations and pollution control, and there is really the need to apply some industrial engineering to increase the efficiency of these work tasks, and also the need to apply industrial engineering to things like hazardous site remediation, asbestos abatement, time and motion, and so on. A common theme in a lot of these environmental sectors is alternatives to the use of chemicals, particularly in the wastewater treatment area, the use of membrane technology and other mechanical alternatives that are used in potentially hazardous or annoying chemicals. The use of ultraviolet, ozone and disinfection for water treatment, for example, is a good area of opportunity. Something like $3 billion per year is spent on membrane equipment systems in the United States, and our survey of this field indicated that there are some technological advances, particularly related to fouling and also chemical compatibility, that would be desirable to membrane technology. The ninth area of research need is expanded real-world application of bioremediation. Specifically, a lot of this technology is still in the experimental stage, and industry would like to see some more real-world application of biotreatment of chlorinated solvents, bioremediation of free metal, and other contaminants. And, the tenth area of research need we identified was in the environmental and industrial noise control field — the practical application of active noise and vibration control. This is an opportunity for mechanical engineering and, in our survey of twelve people in the noise control field, we found eleven who indicated this as a real research need.

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My Environmental Engineering Career: Yesterday, Today, and Tomorrow*

David A. Sonstegard, Cheri L. Kedrowski, and Paul F. Narog

Introduction

As I waited for everyone to arrive, I scanned the room. This was going to be one interesting meeting. With representatives from industry, government, and non-government organizations, I was anticipating a lively discussion (See Table 5-1 - Attendee List.)

Of course, I was also an attendee of the meeting. I am an environmental engineer for Emcorp[2], a manufacturing company. I have developed some expertise in air regulations over the past three years, and was therefore asked to participate today.

The meeting is going to start in about five minutes, and as I am already well-prepared, I allow myself to reflect on the series of experiences that brought me from my school days to today. When I was a university student in environmental engineering, I had no idea that my career would develop this way. Indeed, my career path was but one of many options. A scan across the room reveals a cross-section of environmental practitioners with different skills, backgrounds, and knowledge, representing the wide variety of careers in today's environmental engineering marketplace.

Five minutes before a meeting is not enough time to reflect in detail on the skills I learned in school and the importance of those skills to the on-the-job realities of the environmental field. (And, actually, I should be using this time to network and interact with my peers.) So, in order to demonstrate the role of education throughout my career, I'll instead go back and look at diary entries I have made over the past five years.

Table 5-1
Attendee List[1]

Francesca Loyola	EPA Regional Air Division Director
Mike Borden	EPA Headquarters Office of General Counsel
Jim Porter	State Air Permit Writer
Mahir Thaakar	Local Environmentalist Group Chairperson
Donna Elkington	Emcorp Office of General Counsel
Kenneth Paulson	State Representative
Gina Phelps	Emcorp Public Relations
Julie Cage	State Air Division Manager
Derek Kelley	State Attorney General's Office
Linda Wyndam	Environmental Engineering Professor, State University
Nancy Ward	Consultant, Air Dispersion Modeling
Chi Ting Wu	EPA Headquarters Air Programs
Ethan Salzberg	Emcorp Environmental Engineering Manager (my boss!)
Bill Jones	Emcorp Plant Manager
Harold Weber	Industrial Association Chairperson

Year 1 — The Internship

Following three years in engineering school, I was fortunate to obtain a three-month environmental internship position in industry prior to returning to school this fall to finish my bachelor's degree. I have been on the job for five weeks now and have gained some interesting insights regarding the workforce.

The most noteworthy issue to me is the important role my engineering courses have played in preparing me for the workplace. The shift in responsibilities, from

*Printed with permission from Minnesota Mining and Manufacturing Company.

(1)All attendee names are fictitious. Any resemblance to real names is coincidental.

(2)Emcorp is a fictitious company. Any resemblance to a real company name is coincidental.

studying for myself to working for someone else to produce a product or service, makes the importance of knowing how to apply my education very real. As a result, the internship has helped me to see which areas of study have been especially valuable. It also is helping me to choose what type of elective courses I should take during my senior year.

The importance of chemistry is very apparent. So much of the environmental field revolves around the fate and interaction of chemicals in the air, land, and water. By understanding the chemical make-up of materials, it is easier to understand what is taking place in the environment. For example, the emissions of a particular pollutant, the contamination of soil, or the discharge of chemicals to the local wastewater treatment plant can create complex problems to be solved.

I have also noticed the importance of both written and oral communication skills. Engineers, especially environmental engineers, must interact with people at various positions to get the job done. In the internship position, working with others on teams has been a regular occurrence. I have also been on the phone a lot and had to write letters to the state and federal government. One thinks of engineering as a technical field, but there is much more! "People skills," such as getting along with co-workers, contributing to teams, and being able to accept criticism are very valuable.

As I prepare to go back to school this fall, I plan to work even harder in my studies so that I truly understand and can apply the knowledge I gain. In addition, I plan to use my remaining three electives to focus on the following areas: speech, business administration, and individual project management. I believe such electives will provide valuable knowledge and experience that will help me to become a more effective employee.

As for technical course work, it is difficult to identify other "must-take" courses. At this time, I am not planning on attending graduate school or specialize in a specific area of environmental study, so I will continue with the standard senior year courses in the environmental engineering bachelor's program. This technical education should be sufficient for most entry level environmental engineering jobs. Several of my fellow students are interested in pursuing their masters and doctorate degrees right away, but I want to get some work experience before making a decision to obtain an advanced degree.

I am pleased that I accepted the internship this summer, and I will encourage younger students in the environmental engineering program to gain some initial work experience through an internship position or other employment opportunity. The benefits are numerous; I have learned a lot about how the workforce functions, I have gained important "resume" experience and connections, and I have a clear vision of how to further benefit from my formal education. On a lighter note, I think I'm also going to be better about turning homework assignments in on time. My current project at work has a deadline next Thursday, and it's "for real" — no extensions. Market demands and environmental regulations are much less forgiving than EnvEng 102 teaching assistants.

I have made several friends during my summer job, and I have talked to them about their initiation into environmental engineering careers. Surprisingly, many of them began as interns in process and manufacturing engineering. Positions in the manufacturing arena provide first hand experience as to how waste is generated, why certain pollutants are emitted, how regulations practically impact plants, and where environmental training is needed. If I were a year younger, I would try a position like this for a second internship.

Year 2 — Initial Impressions on the Job

EPCRA, RCRA, CAA, CWA, TSCA, SARA, NESHAPs, NSPS, NPDES, PSD, SWPPP[3] have just completed a three-day environmental training course to which Emcorp sends new environmental engineers, and my mind is spinning with acronyms. The training consists of an overview of federal environmental regulations; about one hour and a half-inch of reading material per regulation. If one does the math, three days of training means that I have received more than enough paper to overflow my briefcase and provide me with some unanticipated weight training. I find it hard to believe that all of this paper is just an *overview* of these regulations!

I had been exposed to many of these regulations while I was in school and during my internship, but I was unprepared for the in-depth regulatory knowledge that my job would require. One of my main responsibilities at Emcorp is to help manufacturing facilities maintain compliance with all environmentally-related regulations. In addition to all those federal regulations, I need to be familiar with state regulations and corporate policies. As if this wasn't enough of a challenge, these regulations are constantly changing. It seems that just as soon as I get a handle on a regulation, the EPA makes a decision to change it, and I'm back to reading the Federal Register with a fine-tooth comb. (By the way, I have discovered the surefire cure for insomnia.)

Unbelievable though it is, my training materials are only a small fraction of the paper I received when I started this job last month. I also inherited a whole cabinet of files that I need in order to do my daily work. These files are related to the recordkeeping, reporting, and monitoring I must do to demonstrate and maintain compliance with all those environmental regulations. In addition to the files that are kept at my desk, Emcorp maintains a central recordkeeping area that contains historical and permanent files. I am encouraged to spend my spare time doing this "light" reading.

Receiving a mountain of files at the start of my job was not particularly encouraging, but paperwork is a reality of this job and most jobs in environmental engineering. Obviously, this is a result of the high degree of government regulation of environmental releases. I have several skills, however, that will make this paperwork more manageable and will allow me to excel in this paper-intensive field.

First, I am really glad that I developed solid reading comprehension skills during school. While some regulatory interpretations are complex enough to require legal guidance, much of the role of my job as an environmental engineer is to read a regulation and establish practical, concrete tasks that will ensure compliance. I must extract the requirements from a myriad of documents, from laws and statutes, to regulations, to guidance memos, to "white papers". Often my job is to explain what I read to process engineers and plant management so that they can understand how regulations will impact them.

Second, I am finding that organizational skills go a long way towards managing all this paperwork. Developing organizational habits while still in school has certainly been beneficial. Merely to save everything I receive is to ensure a live burial in memoranda. Rather, I must be able to assess the importance of documents and know how to access the documents readily when necessary.

Computer skills are also crucial to managing paperwork. Ideally, much paper will be eliminated by the use of electronic filing and storage. For example, I have found that Emcorp does not maintain paper copies of most regulations. Instead, I am expected to access the information via my computer.

Actually, I have to admit that my computer is one of the thrills of my new job. My company has me fully rigged out with a great computer complete with a variety of software. Although the question was not raised during my interview, my company does expect me to be proficient with word processing, spreadsheets, and drawing software. Additional software skills will also come in handy, such as graphing, document management, Internet access, etc. Computers are standard in the at-large workplace today, and the environmental engineering workplace is no exception.

Year 3 — The Routine

I have been on the job for just over one year now. It feels good to have one year of experience behind me. I have become much more confident of my ability to get the job done efficiently. Although there is a tremendous amount of variety in the projects that I do, I admit that my job is starting to feel somewhat routine in nature. I am sure that this is a natural result of my increasing familiarity with my job duties and my growing comfort level as I successfully complete projects. With this confidence also comes the recognition of the skills and attributes I must cultivate in myself to continue to be successful at this stage of my career.

One reality that is apparent is the importance of following the engineering scientific approach to solve problems. Like engineering in general, environmental

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(3)EPCRA - Emergency Planning and Community Right-to-Know Act

RCRA - Resource Conservation and Recovery Act

CAA - Clean Air Act

CWA - Clean Water Act

TSCA - Toxic Substances Control Act

SARA - Superfund Amendments and Reauthorization Act

NESHAPs - National Emission Standards for Hazardous Air Pollutants

NSPS - New Source Performance Standard

NPDES - National Pollution Discharge Elimination System

PSD - Prevention of Significant Deterioration

SWPPP - Storm Water Pollution Prevention Plan engineering issues are complex and require a thorough and systematic approach to solve. I frequently practice the textbook scientific approach - I define the problem, identify possible solutions, obtain data to evaluate the solutions, and finally select and implement the best one. It is not only what I think, but how I think that determines my ability to solve problems.

For example, air emission monitoring requirements for a process line at one of my facilities was very complex in nature, due to a variety of regulations that applied. The equipment needed to be monitored for different parameters, including exhaust temperature and pollutant emission rate. Complicating the situation was the fact that there were multiple requirements affecting each parameter. (The local regulations required that the temperature be recorded each minute, the air permit required that the average temperature be calculated over a three-hour period, and the federal regulations required that the average temperature be calculated monthly.) In addition to monitoring and recording, there were very structured recordkeeping and reporting requirements. These requirements dictated how the information would be stored and later provided to the Agency.

In order to fully understand the requirements and help develop the most efficient compliance program, I systematically attacked the project. I first reviewed all the regulations and permit conditions impacting the equipment, thereby defining the problem. I then looked into the type of monitoring equipment that would be needed to ensure that the required specifications would be met. Next, I helped formulate the data management strategy that we would be following and coordinated the purchase and installation of the equipment. Finally, I participated in the compliance testing that was necessary to ensure that the monitoring equipment was operating correctly. Attention to detail was important, and using the engineering scientific approach helped me to complete the project accurately and efficiently. As this project was related to maintaining compliance, successful completion was critical.

A second reality of my job, one that I recognize is common to all jobs, is the importance of professionalism. Environmental engineers, more so than other engineers, interact with a wide variety of staff positions within a company, from the production line to upper management. In addition, environmental engineers also interact with many people outside the company, be it government agencies, equipment vendors, or engineering consultants. With each and every interaction, I am representing Emcorp, so acting in a professional manner is paramount.

I generally exhibit my professionalism through the good habits I have developed. I follow through on promises, meet deadlines, and arrive on time to appointments and meetings. More intangibly, however, I have a strong work ethic. I am trustworthy, responsible, and committed right from the start. By respecting and valuing my co-workers, I contribute to the open and positive atmosphere in my office. While many of these practices seem to be common sense, I believe that they lead to greater interaction with my peers, increased synergy, and higher productivity.

Year 4 — Greater Responsibilities

Before I began this diary entry commemorating my two-year anniversary at Emcorp, I decided to read my previous entries. I was pleased to observe that the attributes I identified then are still valid today. These skills provided an excellent foundation for the initial stages of my career and will be important to my continued success as an environmental engineer.

However, the routine of yesterday has given way to the new challenges of today. The past six months have been both exciting and hectic. My responsibilities have increased as my knowledge and skills have grown. This increase in responsibility has led to more interesting and complex projects. I now find myself relying heavily on three attributes to succeed: leadership, project management, and team building.

Leadership skills have actually been an important requirement of my job from my first day at Emcorp. Because the environmental field is regulatory based, I frequently make interpretations and decisions regarding compliance issues. While legal counsel can be consulted for assistance, this is not a practical solution on a regular basis. Therefore, even as a relatively inexperienced environmental engineer, I was given an independence and authority that required an immediate demonstration of leadership skills. I took initiative, made important decisions, and was trusted to get the job done.

Coupling initiative with creativity leads to one of the most prized leadership traits in the workforce, innovation. Innovation is a core attribute at Emcorp, one that the company truly prizes. Again, as I gain more experience and knowledge, my opportunities to exercise this unique aspect of leadership will increase. In the long term, I hope to exercise leadership in a more traditional fashion by guiding Emcorp's innovative efforts and by helping other employees succeed in their jobs.

In addition to leadership, I have noticed the importance of having well-developed project management skills. Project management incorporates many of the skills upon which I reflected in previous diary entries — organization, systematic problem solving, written and oral communication. But there are many additional skills I will have to hone to be a successful project manager, such as the ability to plan, to prioritize, and to manage a complex set of individual project tasks that contribute to the greater project goals. I have also registered and am anxious to attend Emcorp's project management training course so that I can learn how to use some of the specific tools that can ease the project management burden, such as software, task planners, charting techniques, etc.

My job, like many jobs, has its fair share of daily "fires" that must be addressed immediately. These can make project management difficult, as they often divert resources and throw the project off schedule. Although they are unplanned, they must be addressed. This is where I hope my prioritization skills will have the greatest benefit. I am learning to resist the temptation to focus on merely urgent tasks instead of truly important tasks.

As my ability to manage projects increases, I am interacting with an ever-broadening group of people to complete my projects. Team building, especially within cross-functional teams, will be a necessary skill to obtain the maximum team productivity. Whether I am a team leader or team member, my ability to respect and value other team members will encourage team synergy, in which the total is greater than the sum of the parts. Some of my most successful teams have been those with the widest cross section and greatest diversity of members. But because our backgrounds were so diverse, we relied heavily on team-building techniques to pull us through our initial frustrations. Quite honestly, the comic strip *Dilbert* is not too far off the mark when it pokes fun at the engineering workplace, and I enjoy my opportunities to work with employees from other disciplines.

I am pleased to observe that the environmental engineering field, more so than just about any other engineering practice, is comprised of a well-rounded and diverse workforce. This diversity of gender, race, culture, and age is beneficial to the field, as the varied perspective produces lively debate and sparks creativity. This diversity puts my office at Emcorp in an excellent position to foster innovation and synergy by fully utilizing the team approach to completing projects.

Year 5 — Future Opportunities

Three years at Emcorp and it's time to celebrate. I finally get three weeks of vacation per year! Three years also marks a milestone in my career, as I was recently promoted to Advanced Environmental Engineer and have been assigned new responsibilities.

I'm so excited about my new job. I am now formally appointed to Emcorp's Regulatory group as an air regulation expert. Throughout my career, I had developed an interest and skill in regulatory work, and grabbed any opportunity to work in this area. Now I will be doing this type of work full-time.

Beginning with my internship, I had been exposed to regulatory work and had observed the bureaucratic nature of the environmental field. (It certainly would be hard to miss.) Rather than being turned off by this aspect of my work, I was intrigued by the challenges it represented. I enjoy trying to find ways to efficiently and innovatively manage regulatory issues in order to give Emcorp a competitive advantage.

For example, my first real exposure to the challenges of the "system" occurred after I had been employed full time by Emcorp. I was asked to obtain a construction permit that would allow Emcorp to make a small change to an existing production process. I was shocked to discover that I would need to complete approximately thirty pages of forms and wait several months for the permit to be issued. My coworkers told me this was only a moderate-sized application!

After three years with Emcorp, I was mature enough to understand the global forces that create bureaucracies. I was therefore willing to take realistic steps as I began to tackle the apparent inefficiencies in the permitting process. First, after a grueling hunt for the appropriate application information, I realized that maintaining information electronically would be one way to improve efficiency. Second, I created a team to address all but a small fraction of the environmental engineering workforce. Even within Emcorp, there is a vast array of environmental careers that deal with issues other than air regulations. Emcorp employs engineers in highly technical areas such as wastewater treatment system design, air emission control, and groundwater remediation. We also employ experts to assist with regulatory issues, spill response, sustainable development, risk assessment, air dispersion modeling, international regulations, and life cycle management, to name a few.

After implementing a myriad of small and large improvements within Emcorp, I began negotiating with regulatory agencies to find opportunities for increased efficiency and cooperation. Although sometimes frustrating, I am encouraged by the progress so far and am looking forward to more such projects within my new job.

My exposure to more and more projects in regulatory work has revealed a fascinating interaction of political, industrial, and public interest organizations. The ability to understand and appreciate these interacting forces will be an integral part of my developing career. As I gain more exposure to these political processes, I see the potential to shift my efforts away from a relatively narrow focus on air regulations towards a broader endeavor of developing collaborative and cooperative relationships among historically adversarial organizations. I am enthusiastic that great strides can be made since sustainable development — protecting human health and the environment so that future generations can meet their needs — is a goal shared by all of these groups. On the distant horizon, perhaps I could extend these endeavors to the international marketplace as Emcorp expands globally.

Conclusion

Given the range of employment possibilities and specific skills needed in the environmental engineering marketplace, no educational program can provide all the knowledge that will be necessary for each of the career choices available to today's graduating engineer. However, developing certain basic skills to prepare oneself to excel within the workplace realities mentioned above would be beneficial to all environmental careers. An environmental engineering education that develops these basic skills — chemistry, written and oral communications, reading comprehension, organization, computer use, the scientific approach, professionalism, leadership, project management, and team building — is one that will prepare the student engineer for a successful career.

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SECTION 2

Educational Approaches and Curricula for the Development of Requisite Skills: Educators' Perceptions

Contaminant Transport, Fate and Remediation: Integrating Measurements and Modeling in Research and Curricula

William P. Ball, Edward J. Bouwer, J. Hugh Ellis, Grant Garven, Charles R. O'Melia, A. Lynn Roberts, Eugene Shchukin, and Alan T. Stone

This paper describes some of the approaches that we are adopting at Johns Hopkins University to bring techniques of measurement and modeling from our research into the advanced undergraduate and introductory graduate curriculum, so that we can hopefully improve the way in which environmental chemists and engineers are being educated. This effort is in its second year of funding through a grant from the Combined Research-Curriculum Development Program that is part of the Directorate for Engineering of the National Science Foundation. Substantial additional funding for the project was contributed by the GWC Whiting School of Engineering at Johns Hopkins.

In keeping with a request from our hosts, we begin with a brief comparison of environmental education at JHU, "then" (30 years ago) and now. Environmental engineering at Hopkins has been strong for many years. In 1966, the more "traditional" components of Sanitary Engineering (led by Dr. Abel Wolman and others at the School of Public Health) were being strongly supplemented by John Geyer and his group, with the latter focusing more closely on better understanding water and wastewater treatment and modeling societal impacts on surface water quality. During this period, there was a strong teaching focus on engineering design for water supply and wastewater treatment (as defined by the classic text by Gordon Fair and John Geyer [see Figure 6-1]).

In more recent times, the areas of interest to environmental engineering and science have continually enlarged, while simultaneously, "cutting edge" research has had to adopt a continually narrowing focus, with

Figure 6-1
Environmental Engineering at Johns Hopkins University: 1966 vs. 1996

1966: Environmental Engineering Science; Sanitary Engineering (SPH)	1996: Department of Geography and Environmental Engineering
Graduate Courses:	**Selected MSE Courses:**
Ecology of Waters	Aquatic Chemistry
Measurement of Water Quality	Environmental Organic Chemistry
Water and Wastewater	Experimental Methods in Environmental Engineering and Chemistry
Water and Wastewater Treatment	Physical/Chemical Processes I
Microbiology of Wastewater	Physical/Chemical Processes II
Systems Analysis in Water Resources	Engineering Microbiology
Design Sanitation Works	Biological Processes
Seminars	Mathematical Foundations for Public Decision Making
	Environmental Engineering Systems Design
	Seminars

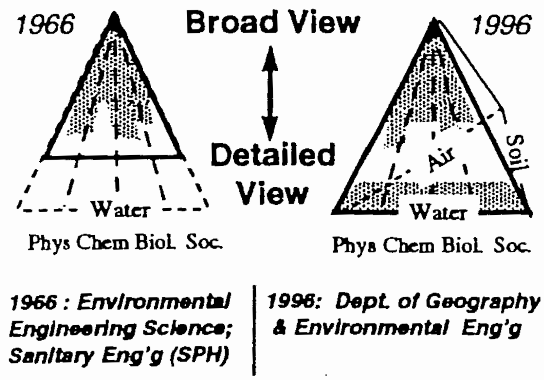
greater specialization of effort. The increased breadth of interest is reflected in our M.S. level graduate courses, where names (and contents) have changed to reflect more "universal" application of the fundamental processes being covered to the subsurface as well as to the surface, and to media other than water (Figure 6-1). While an emphasis on process has characterized the Hopkins program from the beginning, current teaching emphasis has shifted even more toward "concepts" and away from "practices" of design, with the belief that the latter is best learned "on the job", provided that requisite understanding and skills are in place. Concurrently, our research has been faced with the need for increased attention to detail and mechanism, as reflected by a large number of specialized upper-level courses (not shown in Figure 6-1), previously not offered.

The challenge, then, is to teach the concepts of competent problem solving in specific areas (with requisite depth), while still providing students with the "big picture" — i.e., with the breadth of understanding and the needed skills for making management decisions. Fortunately, the problem-solving skills needed for scientific research and professional practice are not really so disparate, and computer technology is helping us to teach across disciplinary boundaries in more efficient ways.

Environmental engineering in 1966, was more narrowly defined, primarily focused on issues of sanitation, water supply, and surface water quality (Figure 6-2). Research focused on "bulk" processes rathen than detailed mechanisms, and improved understanding was still needed at broad levels for the development of better management tools. The introduction of systems analysis into the program facilitated this orientation. Education and research therefore often focused on a "broad view" with occasional emphasis on fundamental scientific questions for which answers were needed to solve particular problems (Figure 6-2).

The 1990's require us to deal with an explosion of new ideas and detailed information that have been developed and obtained over the past three decades, made possible in large part through the vast improvements in computing and analytical capabilities. Measurements and modeling pertaining to environmental engineering have become disciplines within themselves.

Figure 6-2
Environmental Engineering at Johns Hopkins University: "Then" vs. "Now"



Within this context, faculty and students need to maintain a connection with both the broad view *and* with the in-depth inquiry that provides new insight and new options.

The remainder of this presentation focuses on describing a project we have undertaken toward this goal — that is, toward *teaching a better breadth and depth of problem-solving skills by integrating research into the curriculum.*

As we all know, environmental problems are typically complex and multi-faceted. They involve heterogeneous systems, with complex (natural) chemistry, biology, and physics, and they are deeply entwined with societal issues. Most of us (perhaps all of us!) recognize this, and we also recognize the skills that our graduates will need as they begin to tackle these problems.

But are we providing them with those skills as best we might? Environmental engineering and science educators all recognize that the approaches most of us take in training students suffer from some very real limitations. First of all, we typically worry too much about how we can cram all of the essential information into a short semester. We get so focused on imparting the facts that we short change students on acquiring the problem-solving skills that would allow them to deal with new situations (Figure 6-3).

Figure 6-3
Goals of Curriculum Development Project

Provide a meeting place for concepts and practice:

- Open-ended problem solving
- "Hands-on" learning
- Appreciation of limits and uncertainties
- Teamwork and communication skills

Integrate techniques of measurement and modeling (from on-going research) into the "professional" curricula (undergraduate and MSE)

Another factor contributing to the inefficiency of education is that we tend to teach our courses in a format in which students passively sit through lectures, then work on their own through problem sets they have been assigned, which they will hand in a week or two later. There are few technical interactions with others, and feedback is slow to come.

We also encourage students to work individually on problem sets, even though once they graduate, they will more typically have to work cooperatively. Moreover, students can often learn much more efficiently by working in teams, sharing with one another as they develop.

Finally, undergraduate students and professional M.S. students often do not obtain sufficient introduction to research and may tend to view it as an estoteric pursuit, which they do not value highly. They miss exposure to the sort of open-ended considerations that characterize this endeavor, and they lose the opportunity to develop the skills needed to successfully tackle new problems once they leave an academic environment. It is our premise that a better understanding of research (and research approaches) is precisely what students need to better develop some currently neglected skills.

In response to these problems, we at Johns Hopkins are trying to change the way in which we are educating environmental engineers and scientists so as to better incorporate research into the advanced undergraduate and introductory graduate curriculum. The basic philosophy that we are adopting can be described as follows:

- Pure scientists study and understand individual phenomena and generate basic information, but they rarely have experience with complex, "real" systems and may be unaware of what information is most critically needed.

On the other hand, modelers develop mathematical expressions that account for a large number of contributing phenomena in a useful and robust manner, but they are typically unfamiliar with conducting measurements and may be unaware of the limitations that accompany different kinds of laboratory and field observations.

- We believe that the processes of making measurements and constructing quantitative models are complementary activities: without models, measurements have no context; without an appreciation of those processes through which input parameters are determined, model output is of dubious value.
- Introducing our students to both activities in an integrated fashion will address this need, and will simultaneously serve as an introduction to the basic tools that define our research. By integrating our research with the curriculum, our students will learn through "real" and relevant applications, involving more open-ended types of problems. We hope that such problem-solving will foster a spirit of inquiry that will stand them in good stead in future careers as environmental scientists and engineers.
- The basic theme we have adopted — since this represents the principal research area of the eight faculty members that are involved in this project — is one of contaminant fate, transport, and remediation, which thus straddles the fields of environmental engineering and environmental chemistry.

The approach we are taking in this Combined Research-Curriculum Development Project is to:

- develop a new lecture course in Environmental Systems Analysis and new laboratory courses in Environmental Chemistry (covered in more detail subsequently);
- modify existing lecture courses to include computer modeling exercises and experimental data from our research;
- use funds obtained from NSF and from the JHU Whiting School of Engineering to:
  - purchase new analytical equipment that will be used in the laboratory courses. To date, we

have purchased two research grade capillary gas chromatographs (with autosampler, FID and ECD detectors) and an HPLC system (w/ a UV/visible absorption detector), networked to a common PC-based data acquisition system; this coming year, we intend to purchase additional HPLC equipment and, potentially, a supercritical fluid extraction device;

- substantially upgrade our departmental computer laboratory. We have purchased most of an expected ultimate allotment of approximately 7 to 8 Pentium grade PCs, the same number of Macintosh Power PCs, portions of 2 Silicon Graphics Indigo workstations, as well as an LCD viewer so that we can demonstrate models in the classroom; and
- equally important, these funds have allowed us to dedicate most of a full-time technician's time toward course related issues, including maintenance of the analytical instruments and the computer laboratory, and the provision of software and hardware assistance to students and faculty.

Two of the more important new courses developed under the grant are:

- *Environmental Engineering Systems Design* (Figure 6-4). This course is a required course for Environmental Engineering minors, and is typically taken at the senior level, or as part of a "systems" requirement for our entering M.S. students. The course, managed by Professor Hugh Ellis, introduces concepts of operations research and systems analysis in the context of multi-faceted environmental problems and team effort.
- *Experimental Methods in Environmental Engineering and Chemistry* (Figure 6-5). This course provides an introduction to analytical methods of environmental chemistry in the context of contaminant fate and process understanding, with a very strong emphasis on demonstrating how laboratory measurements are used in making engineering decisions. The course, managed by Professor Lynn Roberts and Alan Stone, is required of all M.S. students, but is open to undergraduate students who have already had our 1-credit introductory laboratory in Environmental Engineering. Typically, most "wet" faculty also strongly encourage their Ph.D. students to take the course, and most are happy to do so.

The goals of the Environmental Engineering Systems Design course were to introduce students to the field of operations research/systems analysis, and to use the technical skills learned in the course in a comprehensive team project setting. Topics presented in the course include linear optimization, nonlinear optimization, multiobjective programming, stochastic optimization, dynamic programming, game theory, and selected principles in applied probability and statistics.

Figure 6-4
Environmental Engineering Systems Design

Principles of operations research and systems analysis

- Linear and nonlinear optimization
- Multiobjective planning and game theory
- Dynamic programming and stochastic optimization
- Selected principles in applied probability and statistics

Team projects, 2-3 students each

- Power plant siting
- Reservoir sizing and operation
- Forest management
- Ambulance facility siting
- Groundwater monitoring network design

Realistic problem statements

"Full-blown" modeling approaches

Students gain:

- Programming and optimization skills
- Experience in building realistically-sized models
- Appreciation for uncertainties and open-ended problem solving
- Appreciation for the process of communication sophisticated modeling results in policy relevant ways

Modeling was integrated into the course via the team projects. The class of eleven students selected five projects (from a larger list drawn from past and ongoing research in the Environmental Systems and Economics Program in the Department; students were given the choice of all working on one project, or forming teams of two or three, and selecting their own project — they chose the latter option). The projects were:

(1) power plant siting

(2) reservoir sizing and operation

(3) ambulance facility siting

(4) forest management

(5) groundwater monitoring network design.

Figure 6-5
Experimental Methods in Environmental Engineering and Chemistry

Familiarize students with

- Analytical methods and techniques
- Data analysis, error, uncertainty
- Measurement application in context of modeling (contaminant fate and transport)
- Scientific method and research approach

Seven formal labs plus independent project

- Seven formal laboratory exercises:

  System response to acid input (2 labs: pH/alkalinity)

  Cobalt solubility in open systems (AA)

  Kinetics of chromium oxidation (UV/Vis spectrophotometry)

  Influence of chemical structure on air: water partitioning (GC)

  THM formation in drinking water (GC)

  Influence of K_{ow} and pK_a on the transport of ionizable organic chemicals (HPLC)

- Independent project

  Problem of students own selection

  Hypothesis must be formulated and tested

  Results reported in publication format

Students gain:

- Analytical skills
- Appreciation for uncertainties, levels of effort
- Open-ended problem solving in both team and individual settings
- Experience with designing research project
- Communication skills

Projects (1) and (2) required the formulation and subsequent execution of relatively large linear optimization problems (well beyond the size for which manual computer entry is feasible, involving problems with 500-1200 variables in 300-1000 constraints). Projects (3), (4) and (5) involved the formulation and solution of large integer optimization problems. Project (5), as well, required the repeated execution of a groundwater flow simulation model (SUTRA), embedded within an 'outer' integer optimization shell.

The students in the course last year were primarily undergraduate engineering students. The students were given highly realistic problem statements, and the modeling tools they were given were some of the same as used in professional practice or graduate research (not "watered-down" versions). The students showed considerable enthusiasm and dedication to their work, and generally demonstrated that the class *could* successfully proceed at this level.

Students gained from the course greatly enhanced computer and optimization skills, experience in building and executing realistically-sized models, and an appreciation for the processes involved in communicating sophisticated mathematical modeling results in policy relevant ways.

The lectures to the Experimental Methods in Environmental Engineering and Chemistry class emphasize how laboratory measurements can provide the information needed to model environmental fate and make engineering decisions. Knowing how data will be used helps the lab researcher decide upon the sampling program, the sample work-up, and the choice of analytical method, and all of these aspects are covered in the laboratory exercises.

Seven formal laboratory exercises are designed to provide students with the opportunity to discuss what each analytical technique tells them about the sample (and what it doesn't tell them). The last four weeks at the end of the semester are allocated to independent (individual) projects, in order to give students first-hand exposure to the scientific method and the opportunity to grapple with issues of data precision and uncertainty in a context of their own choosing

Laboratory exercises are all designed around the measurement of environmentally relevant information, such that analytical methods are taught within the context of their application. Through the class lectures and the associated laboratory exercises, students gain an appreciation that laboratory approaches (and required levels of precision) may be quite different for the determination of chemical properties and parameters (e.g., Henry's coefficients or kinetic rate constants) relative to the techniques used to answer broader questions about system response to change (e.g., pH changes with acid addition or THM formation as a function of water quality). In all of the laboratory exercises, issues of uncertainty and data analysis are emphasized. Many of the laboratory exercises are designed such that the same chemical properties of concern in an environmental context (e.g., vapor pressure or hydrophobicity) are explicitly important to the analytical method being explored (e.g., GC or HPLC retention). Since students also work in small groups for the formal labs, these exercises also promote team skills.

The independent projects give students a personal experience with the formulation of scientific hypotheses and the design of experiments to test them. Students design their own sampling strategies, interpret their results, and write up their projects in a format suitable for publication.

It is our hope that the course experience will give students a better appreciation for the principles and techniques behind laboratory measurements, including a better understanding of uncertainties and the levels of effort required to obtain accurate and meaningful results. Both the formal laboratory exercises and the independent project allow ample opportunity for open-ended thinking, application of the scientific method, and the communication of complex technical issues.

An additional course being planned is Colloid Chemistry in Environmental Engineering. Dr. Eugene Shchukin (a distinguished Moscow State University scientist who is with us 8-months of the year) is developing this course considering the universally disperse (microheterogeneous) state of matter in nature and technology, and the predominant role of surface phenomena in controlling the properties of disperse systems (sols, sediments, emulsions, foams, aerosols, thin films). Special attention is paid to stability, surfactants, and structure formation in colloid systems. The course includes the molecular dynamics (numerical) simulation of wetting, adsorption layers, particle interaction, environment-sensitive mechanical behavior, and laboratory demonstrations of surface tension and colloid particle adhesion measurements.

Dr. Lynn Roberts also plans to develop a new environmental chemistry lecture course, Transformations of Organic Contaminants, to be introduced during the spring semester. This course, which will be aimed at more advanced graduate students, will emphasize the development of a detailed understanding of the biochemical and abiotic pathways through which anthropogenic contaminants undergo transformation. This mechanistically-based understanding will lead to a discussion of how structure-reactivity relationships can be applied to abiotic transformations of organic contaminants, or how the physical and chemical properties of contaminants influence their biological activity through Quantitative Structure-Activity models. The course will also address the following:

- Transformation pathways; relationship of physical/chemical properties to transformation kinetics
- Problem applications using structure-activity models

Many of our upper level undergraduate and first-year graduate courses are undergoing substantial modification to (Figure 6-6) include computer modeling exercises and laboratory-based measurements. Such modeling enables an interactive learning process that should help reinforce concepts developed in lecture and the understanding acquired through manual calculations. With the computer-based tools, students can easily ask themselves: "what would happen if I changed this one parameter", run a quick computer "experiment", and develop a more intuitive grasp of the relative importance of different processes in contaminant fate or treatment.

For example, Professor O'Melia is currently working toward the integration of a lake modeling program (developed by R. Schwarzenbach and others at EAWAG) into his undergraduate (junior level) engineering course. Professor Ball has integrated modeling exercises into an M.S. level course that provides interactive diffusion modeling (using a YOW! application developed by P. Roberts and others at Stanford University[1]), as well as interactive counter-current packed tower design exercises (Air Stripping Design and Cost program, developed by D. Dzombak and co-workers at Carnegie Mellon University).

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[1]NB: Regrettably, the YOW! programming environment is no longer being supported by Stanford's Academic Information Resource group. For future computer modeling exercises in this course, Professor Ball anticipates developing interactive problem sets with commercial numerical simulation software.

Figure 6-6
Course Modifications

Introduction to Environmental Engineering and Science
(C. O'Melia)

- New modeling exercise (Chem Zee)

Groundwater Contamination (G. Garven)

- Expanded set of groundwater models

Physical/Chemical Processes in Environmental Engineering
(W. Ball)

- New modeling exercises (diffusion, air stripping)

Engineering Microbiology (E. Bouwer)

- New laboratory investigation of contaminant biodegradation

Synthetic Chemicals and the Environment
L. Roberts/A. Stone)

- New modeling exercises (e.g., ClogP)

Aquatic Chemistry (A. Stone)

- Enhanced exercises demonstrating computer application to equation solving

Environmental Inorganic Chemistry (A. Stone)

- Enhanced emphasis on application of research tools to professional practice

Environmental Organic Chemistry (L. Roberts)

- New computer modeling exercises (Hyperchem; ClogP; MASAS)

These modeling exercises, while not far beyond what we previously had been trying to accomplish in our courses, have been facilitated by the NSF grant — i.e., by the enhanced computer facilities, LCD viewer, and additional computer technician support.

Similarly, the grant has facilitated the inclusion of an additional laboratory exercise in Professor Bouwer's Environmental Microbiology course, designed to integrate research-based understanding of contaminant biodegradation and test methods into the M.S. curriculum.

Four environmental chemistry courses are going to undergo substantial modification to include computer modeling exercises.

- *Synthetic Chemicals and the Environment* is aimed at upper level undergraduate students in Chemistry and Chemical Engineering. It couples an understanding of the fundamentals of environmental chemistry with that of industrial chemistry — how chemists go about designing products for a given application, within the context of how chemical design dictates environmental fate.
- *Aquatic Chemistry* is an advanced undergraduate/ introductory level graduate course that emphasizes the calculation of chemical equilibria in simple and complex systems. Students are encouraged to write their own simple programs (e.g., in BASIC or in spreadsheets) and to justify the quantitative approach they choose to take. In Fall of 1996, we plan to include laboratory demonstrations and classroom discussions about how thermodynamic information is obtained, and the uncertainties they introduce. The class will lead in well to the new laboratory course offered in the following semester.
- *Environmental Inorganic Chemistry*, together with *Aquatic Chemistry*, forms a two-semester sequence. This course has emphasis on developing an understanding of the thermodynamics, kinetics, and mechanisms of reactions, and also addresses the topic of surface chemistry. This course was revised last semester to take advantage of the enormous advances in computer models to describe the adsorption of metals and ligands onto surfaces (such as *HYDRAQL* and *FITEQL*), as well as reaction kinetics related to chlorination reactions.
- *Environmental Organic Chemistry* has been significantly augmented through the application of computer modeling exercises, using desktop computational chemistry software (Hyperchem) and chemical fate models (e.g., MASAS, developed at EAWAG to simulate chemical behavior in lakes). In many cases, the modeling exercises from this class have been selected to integrate with the measurements made in the laboratory class.

There are a number of additional activities we are going to engage in as part of this Combined Research-Curriculum Development Project. These include fostering increased participation of industrial and government environmental engineers and chemists through a rotating seminar series. A workshop was held in March of 1996 for interested educators and industrial participants, and some of these findings were disseminated there. At the same time, we heard from 6 industrial representatives about their views of graduate needs and how our program might best meet them. Most of this feedback was quite positive, and the primary message seemed to be to continue in this direction. However, other needs not addressed by our current project were also raised, including many that have been discussed at this conference. Key among these are the need for better college preparation for entering undergraduate students, as well as strengthening of fundamental skills in the earlier undergraduate years.

We also plan to disseminate the results of our project to the academic community by developing workbooks (containing solved problem sets and computer exercises) and lab manuals (containing details of experiments, along with example data) that will be made available at cost to interested parties in print format, as well as in electronic format, in order to facilitate their adoption by others. Professor Lynn Roberts has completed one such workbook for her Environmental Organic Chemistry course. The workbook is currently available and can be ordered through the Department at cost.

Another activity planned is the development of a World Wide Web page describing the curriculum developments. One web page has already been created (http://www.jhu.edu/~environet/), designed to assist students in finding and organizing some of the environmental engineering information available on the Internet; however, we are also hopeful of better using the Internet to disseminate project-related information and developments.

It is our belief that the integration of research approaches to measurement and modeling have provided a useful context for more open-ended problem solving, hands-on experience, and team effort. Students gain appreciation of what is known and what is not known; for uncertainties and for the level of effort required to reduce those uncertainties. Perhaps most importantly, they gain a sound appreciation of how their knowledge and conceptual understanding can be applied to the solution of complex and ill-posed problems, and of the need to communicate both the results and the uncertainties to others.

Important challenges remain for the continuing refinement and maintenance of our curriculum. There are some difficulties related to maintaining software and hardware, to the "learning curves" on these items for students and instructors, and to the time and money devoted to these issues. We have been lucky to have circumvented many of these issues, thanks to good students, reasonable class sizes, good assistants (technicians and teaching assistants), and good financial resources for equipment and supplies. In the latter two, we have found the NSF grant enormously helpful.

Although continuation of the effort should not be as demanding as its initiation, we do have concerns with regard to the long-term overhead costs (e.g., technician, supplies, equipment maintenance and upgrades). Hopefully, NSF and other federal agencies will remain viable sources of such funding in the years to come. Alternatively, our industrial partnerships will need to take on new dimensions!

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Process Fundamentals: Skills for a Lifetime of Practice

Francis A. DiGiano

Tried and True Technologies?

As I was about to prepare my presentation, the arrival of the July 1996 issue of *Water Environment & Technology* with its theme of "Tried and True Technologies — Industry Values Methods that Work" struck a discordant note. In introducing the theme for articles in that issue, the editor states:

> "The industry has good processes that work. Some modifications have been made to handle nontraditional pollutants such as phosphorus and toxics, but overall, plants across the country are using the same natural cleaning processes for domestic wastewater...No one seems to be trying to jump hurdles to reach the patent office and proclaim the revolutionary wonders of the latest advance."

My presentation is contrary to the tried and true technologies theme. For new technologies to evolve in practice, I believe that we need to strengthen the focus on teaching of fundamentals, with liberal use of applications to demonstrate their importance. Ironically, one of the articles in the issue of *Water Environment & Technology* which advocates tried and true technology particularly supports the importance of fundamentals. This article deals with lasers to measure dispersion at submerged discharge outfalls in hydrodynamically-scaled physical models and fluorescent particle tracers to measure dispersion in field studies (Roberts and Ferrier 1996). It points out quite appropriately that existing mathematical models of dispersion are not very reliable because the hydrodynamics at outfalls defy easy description (e.g., the influence of currents and density differences are not easy to predict); thus we need experimental measurements. New measurement techniques are not only useful for understanding the dispersion pattern at a particular site, but they can also improve our conceptual understanding of hydrodynamics. The result could be generalization of observations and better predictive models. To exploit measurements from lasers and fluorescent particle tracers to the fullest, the environmental engineer/scientist should be well-grounded in fluid mechanics and curious about how to generalize dispersion results from observations in one particular setting.

In the broader context of graduate training for environmental engineers, the skills we should provide are rooted in fundamentals and scientific curiosity. These skills are relevant not only to process engineering but to systems analysis (inclusive of environmental planning) and transport/fate modeling of natural systems (inclusive of engineered-natural systems). They will be discussed primarily in relation to the M.S. degree program at the University of North Carolina. However, the Ph.D. degree is increasingly valued in practice because applied research may be needed to solve increasingly more complex problems. The skills of a Ph.D. graduate may be more specific to the dissertation topic but there should be less debate as to the importance of strong general training and awareness of fundamentals as well as scientific curiosity.

Evolution of Teaching Process Fundamentals

The teaching of process fundamentals in environmental engineering has undergone remarkable change over the last 30 years. As a doctoral student at the University of Michigan in 1966, I can well remember presenting a seminar to my fellow graduate students on applications of material balance concepts that I had just learned from my chemical engineering class; they were impressed. Our field was relatively rich in experimental laws (e.g., for hydraulics of clean filters) and performance correlations (e.g., performance-loading relationships for trickling filters) but poor in theory with a few notable exceptions such as attempts to formulate kinetics of BOD exertion and of flocculation

(Smoluchowskis theory from the early 1900s). Environmental engineering was truly more art that science but it is not to denigrate the contributions to process theory from giants of the field like Gordon Fair in the 1940s and 1950s. In fact, who among us contemporaries has a correlation, equation or theory that bears our name?

Chemical engineering, with its emphasis on material balance and kinetics, provided a fundamental approach to reactor design that was embraced in the late 1960s by environmental engineers. However, to apply reactor theory to engineered and natural environmental systems required considerable adaptation because unlike reactors in the chemical industry, the feedstocks, products and kinetics were not well understood *a priori* and moreover, unsteady state rather than steady state is a common condition. Nonetheless, students in environmental engineering were introduced to chemical engineering principles with the hope that simplistic reactor theory could be adapted to more complicated systems. We were successful to some extent as a result of much research in the 1970s. For instance, the field of mathematical modeling blossomed along with a new lexicon that included such terms as *parameter estimation, calibration, verification* and *algorithms.* There were many who challenged the predictive capability of models given the complexities of real environmental systems — and this is still true today.

Fate and transport modeling became important as we wrestled with trace levels of specific anthropogenic chemicals in natural systems and burgeoning concern over groundwater contamination. Unfortunately, in my view as an academician, the term *hazardous waste* popularized this era. It confused students by creating an unnecessary and quite artificial boundary for teaching process fundamentals and led to the creation of *stand-alone* curricula to attract students. We resisted this trend at the University of North Carolina. In fact, the same fundamentals apply to treatment of *hazardous wastes* as would removal of any other contaminant, albeit a much deeper foundation of fundamentals may be needed (e.g., properties of supercritical fluids that affect separation and transformation of contaminants).

The teaching of process fundamentals was further impacted as the artificiality of the dividing line between processes in engineered and natural systems became more obvious. *In-situ* remediation of contaminated groundwater is a good example. In this connection, better understanding of multiphase systems (both natural and engineered) emerged in the 1980s as a critical need if environmental engineers were to predict the exposure of humans as well as lower life forms to anthropogenic chemicals. Environmental engineers typically had only limited knowledge of multiphase systems such as those involving oxygen exchange at air/water interfaces and perhaps adsorption of organic chemicals onto activated carbon. More sophisticated courses evolved to include complex equilibria and kinetic relationships governing distributions of chemicals among air, water and solid phases and fundamentals of multiphase flow (e.g., as would be important in groundwater highly contaminated with nonaqueous phase liquids and in remediation schemes that involve surfactants).

The technology options in engineered systems have also expanded greatly since the 1980s. I include here systems used for *in-situ* and *ex-situ* remediation of contaminated groundwater. This has required greater emphasis on teaching of more sophisticated phase separations (e.g., by membranes and air stripping) and transformations (e.g., light irradiation of TiO_2 particles and enzymatic oxidation reactions). For many of these new technologies, the limitation of process rate by mass transfer became very important to understand in both engineered and natural systems and this led to further sophistication in teaching of fundamentals.

Most recently, uncertainty principles for dealing with spatial and temporal variability in system coefficients (i.e., the *stochastic* nature of many environmental systems) have become more widely recognized as important to teach our students. This takes students well beyond the classical tools of statistical analysis. A good example is analysis of the spatial distribution of soil characteristics which influence water transport and sorption of contaminants in the subsurface environment; for this, very sophisticated approaches such as *random field theory* have found increasing application. It also necessarily leads to philosophical discussion about the scale at which system characteristics need to be resolved to estimate performance within reasonable tolerance for decision-making. Use of the terms *micro-*, *macro-* and *megascales* provide a way for students to qualify system behavior and to think more generally about the need for resolution of system coefficients.

Why are Process Fundamentals Important?

Process fundamentals cover the transport, separation and transformation of contaminants in natural and engineered environmental systems. The more unified the approach to teaching them, the more clearly will students realize that a common set of principles can be applied to practical problems regardless of the medium (air, water, various solids, NAPLs, etc.). Students should understand the motivations for change in contaminant concentration and form in order to develop the skills to answer the practical, engineering-oriented questions of how to control that change in myriad situations. Innovations in treatment technology cannot occur unless the factors controlling change in environmental systems are understood through study of energetics, kinetics and reactor dynamics. The same knowledge is needed to provide an accurate assessment of the impacts of human activity on the environment (the fate and transport issue). Moreover, we can expect the array of processes used by environmental engineers in practice to grow, requiring a stronger grasp of fundamentals in such areas as catalysis (both abiotic and biotic) and multiphase distributions. Finally, process fundamentals are important for environmental engineers who want to work in the growing field of industrial waste minimization. Environmental engineers can play a role alongside chemical engineers if they appreciate, for example, through structure-activity relationships, how reagent substitutions will affect downstream treatment processes and how to select a process within the plant for product recovery.

I would be remiss in not stressing that process fundamentals also provide a way to counteract the tendency for over specialization in our field. The rapid expansion of science and engineering knowledge has fostered this specialization, the downside of which is the silos of knowledge syndrome, i.e., inability of co-workers to understand what each contributes to a problems solution. The goal in a sequence of process engineering courses is to avoid segregation of knowledge into small, disparate units and instead to return as often as possible to a common, strong foundation of fundamentals. This foundation is equally important for keeping technical communication open among university colleagues who seemingly conduct research in disparate areas and for dialogue with non-specialists, e.g., environmental regulators.

The Program at the University of North Carolina

Elements of environmental engineering are found in two programs within the Department of Environmental Sciences and Engineering. These are the Water Resource Engineering (WRE) and Air, Industrial, and Radiological Hygiene (ARIH) graduate programs. Unlike most universities, we rarely have undergraduate students in our courses because the University of North Carolina at Chapel Hill does not have an undergraduate engineering curriculum. The tendency among our faculty, therefore, is to assume a very mature audience, already strongly focused on a career as environmental engineers. As important, our M.S. level students must engage in some form of investigative study (3 to 6 credits); up until the present, the *de facto* requirement had been 6 credits. These two factors — only graduate students in our department programs and independent study at the M.S.-level — account for presentation of fundamentals at a fairly challenging level in process engineering and related courses.

Appendix A is a description of the curriculum in the WRE program. The only requirement that is common to all MS students is for a 3-hour class in statistical methods; several such courses are available. Table A-1 is a list of nearly 50 hours of Core Engineering classes from which MS students must choose at least 15 hours. This listing is quite diverse and inclusive of several air engineering courses to encourage closer ties with the ARIH program. We intentionally have avoided the rigidity of requiring specific core courses because of the varied interests of graduate students and the diverse nature of the water resources engineering field. Table A-3 provides a listing of 15 hours of core engineering courses and electives taken by students with an interest in the following areas of specialization: Hydrology and Contaminant Transport; Water Resources Systems Analysis and Planning; Industrial and Hazardous Wastes; and Water and Wastewater Treatment Processes. This table demonstrates not only the diversity of our program but also that certain process fundamentals are common to several of the areas of specialization. The ARIH program is more structured with 9 hours of common required courses and additional required courses depending on specialization area.

Table A-2 of Appendix A is a list of elective courses for WRE students. These include courses in biology, chemistry, advanced mathematical methods, operations research and econometrics. MS students would typically take 6-9 hours of courses from this list.

Our first course in process fundamentals is ENVR 171-Reactor and Mass Transport Principles although a more appropriate title might be Process Dynamics in Environmental Systems (Weber and DiGiano 1996). Students are taught here that environmental engineering builds upon a fairly well-defined set of principles from physics, chemistry and biology, aided by skills in mathematics and engineering problem solving. Applications to both natural and engineered systems are given in this first course. Although mainly populated by WRE students, this course appeals to some engineering students in the ARIH program; we hope this trend will continue.

Follow-up courses then provide more specificity to physical, chemical and biological systems used in environmental engineering (e.g., ENVR 274, 275, 276 and 277). In addition, courses in the hydrology and contaminant transport area expand greatly on ENVR 171 to stress differences between continuum and stochastic approaches, the importance of boundary conditions and transient conditions, the formulation of sophisticated hydraulic and contaminant transport models and most recently, approaches to solving multiphase flow and transport problems. The last of these challenges students to integrate their knowledge of statistics, mass transfer phenomena, physical chemistry and thermodynamics. Limitations to experimentally-based laws (e.g., Darcys Law and Ficks Law that only apply to a single phase) are explored in light of new concepts to consider mass, energy and momentum balances together with thermodynamically-based equations of state and constitutive relations (e.g., pressure-saturation-permeability) for complex mixtures. These fundamentals are all necessary to advance models for predicting the effectiveness of remediation schemes upon which many engineering decisions are based.

A common feature of several engineering courses in our program (ENVR 217, 272, 273 and 276) as well as other electives is an emphasis on case studies and reading of the scientific literature. The intent is to complement and reinforce presentation of fundamentals in other courses. Students become comfortable with their ability to read the scientific literature which provides another means for continued learning later in their careers. Case studies are often open-ended, practical engineering problems that might involve teams of students working together to solve and present to the rest of the class. This allows for integration of technical knowledge with issues of societal and regulatory importance; moreover, it assists students in polishing their communicative skills. A rather unique feature of ENVR 273-Water and Wastewater Treatment Plant Design is that two consulting engineers each volunteer two weeks of their time to teach this intensive case-study course during the first summer session; visits to treatment facilities are included.

The Future

I have put forward the view that a solid understanding of fundamentals obtained at the M.S. level in environmental engineering provides the skills for a lifetime of practice. For this view to prevail, undergraduate students must be even better prepared in the future. Undergraduates need a solid grounding in the engineering sciences and related basic sciences but they should also be more liberally educated in order to put the engineering profession in proper perspective with social values, human behavior and the history of humankind. Perhaps a four year program is not sufficient. Students need to collocate the fundamentals of mathematics, physics, chemistry and biology more effectively into a usable body of knowledge that will counter the disturbing trend toward the silos of knowledge. Although I have stressed fundamentals, the future of education also depends on convincing students that, in fact, these fundamentals result in solution to real problems. For this to happen, we need more interaction with practitioners who are truly convinced of the importance of these fundamentals, and more practitioners with this mindset.

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Environmental Engineering Education the Evolution of Curricula

C.P. Leslie Grady, Jr.

Thirty plus years ago a revolution occurred in environmental engineering education that has allowed the continual evolution of curricula in response to the changing needs of society. That revolution was a shift in educational emphasis from the transfer of empirically-based practice to the grounding of curricula in fundamentals that foster creative problem solving. Instead of giving students ready-made solutions to a limited number of problems, we began to give them a set of skills, tools, and techniques from which they could create their own solutions to an almost infinite variety of problems. As a consequence, as the multiplicity of problems faced by environmental engineers has expanded in recent years, educational programs have not had to be totally revamped. Rather, educators have been able to respond by expanding the breadth of the fundamental base, thereby making it possible to build new skills in the students in an efficient manner. In the following, I will review very briefly the curricular changes that have occurred and then devote the majority of my remarks to our emerging curriculum at Clemson University as a way of delineating our assessment of the knowledge and skills required by our graduates.

The revolution in environmental engineering education was the result of the efforts of a large number of educators who recognized that environmental engineering was expanding and that the traditional educational approach of problem-focused courses was too inflexible to incorporate the expansion efficiently. The focus on fundamentals that characterized the revolution occurred in two ways. First, a stronger scientific base was adopted, with the result that chemistry and biology became more important relative to physics, upon which most engineering education and practice is built. It should be noted, however, that the importance of chemistry was recognized earlier than the importance of biology and that even today many environmental engineers receive relatively weak education in biology. Nevertheless, our educational programs continue to evolve and one characteristic of that evolution is increased emphasis on the sciences. Second, a unit operations approach was developed that built on the sciences and presented the principles upon which environmental control processes functioned, regardless of the context in which they were used. When combined with a capstone design course that focussed on the strategy of process engineering, the new environmental engineers were able to organize unit operations into efficient processes for situations that had not been encountered before. In other words, they became the creative problem solvers that are still desired today as the outcome of engineering education.

The revolution in environmental engineering education came about as I moved from undergraduate to graduate school, and in fact, Gene Rich's seminal unit operations text was published the year I received my B.S. degree. Thus, in a sense, I grew up with the "new" approach and have always found it to be logical. Furthermore, I was very fortunate to take my first teaching position at Purdue University just at the time that they were revising their curriculum to adopt a unit operations approach built on a strong science foundation. Consequently, I had the opportunity to develop totally new courses that integrated operations from water treatment, wastewater treatment and air pollution control. That experience reinforced my belief that it is possible to educate environmental engineers to work across all media by drawing upon fundamental principles. Furthermore, I believe that such an approach has made it possible for us to integrate new areas into our curricula with a minimum of effort by emphasizing certain new operations while de-emphasizing others that are no longer used frequently.

While I am a firm believer in the unit operations approach to the education of environmental process engineers, one change that has occurred over my career is an expansion of environmental engineering to encompass many areas other than process engineering.

While those of us who design the processes that treat drinking water, clean wastewater, eliminate air pollutants, and remediate contaminated soil and groundwater still play a major role in our profession, many other functions of environmental engineers and scientists require other skills. Thus, unit operations courses are not appropriate for them and need not be in their educational program. All tracks, however, must be built on the fundamental sciences because all environmental problems involve living systems and we cannot analyze and understand them without a sound foundation in chemistry, biology, and physics.

The current pressure on engineering education is for increased emphasis on the building of certain general skills, such as written and oral communication, teamwork, adaptability, leadership, and an ability to interact cross-culturally. Because of the importance of those skills and the advocacy of them by members of departmental and college advisory committees, there will be a tendency to put more emphasis on them at the expense of technical knowledge transfer. We must resist that tendency. The development of those skills is the responsibility of the entire educational system. While we must do our part by adopting exercises that integrate them across our curricula, we who teach at the graduate level must not dilute our efforts to develop our students' technical abilities in a misguided effort to remediate past educational deficiencies. The world cries for sound technological solutions to our environmental problems and we must help our students gain the ability to develop them while giving them the foundation upon which to build a lifetime of learning.

With these thoughts in mind, I would now like to review what we are doing at Clemson, where we are currently revising our curriculum. We identified five areas of environmental engineering and science within which we have the skills to educate students: process engineering, environmental chemistry, contaminant fate and transport, nuclear environmental engineering, and waste management. We then identified the knowledge, skills, and abilities (KSA) that should be acquired by graduates in each of those areas before entry into the workplace. Finally, we reorganized our courses to present those KSAs as efficiently as possible, while recognizing that all courses must develop certain nontechnical skills, as noted above. That exercise resulted in a change in our educational approach. Whereas in the past we had a very open curriculum with few required courses for the M.S. degree, we are now moving to a much more structured curriculum to ensure that every student masters a coherent body of knowledge and departs with well defined technical skills that will allow him/her to practice in one of the specialty areas. To do that, all M.S. students in the department are required to take three core courses that present the fundamental underlying principles that are common and essential to all specialty areas. In addition, each of the specialty areas contains at least three required courses, resulting in six of the eight courses in a typical M.S. (with thesis) plan of study being required. The other two courses must be selected from a list of suggested courses for the particular specialty area.

Table 8-1
Core Courses Required of All M.S. Students

Principles of Environmental Engineering

- Review of fluid mechanics
- Process characterization
- Material balance relationships
- Macrotransport processes
- Microtransport processes
- Reactor engineering/modeling

Principles of Environmental Chemistry

- Kinetics
- Thermodynamics
- Chemistry of aqueous systems
- Chemical matrix concepts
- Acid/base reactions
- Complexation
- Phases and interfaces
- Redox reactions

Principles of Environmental Biology

- Cell physiology
- Nutrition, growth, and death of microorganisms
- Energetics
- Biosynthesis
- Microbial kinetics
- Toxicity and inhibition
- Microbial ecology

Table 8-1 presents our three core courses, showing the major elements of knowledge that are imparted in each. The first two courses have been required in our curriculum for many years, but have been revised to ensure that their contents reflect the KSAs common to all areas. The course in environmental biology is being required of all students for the first time, although it has been required of process engineering students for a decade. While most of it is focussed on environmental microbiology, the coverage has been expanded to include cellular processes in higher life forms, helping to prepare students to understand the physiological aspects of risk assessment. Excellent textbooks are available for both environmental chemistry and environmental engineering principles, but that it not yet the case for environmental biology.

Table 8-2 presents the required courses for the process engineering area. Because physico-chemical unit operations are essential to all process engineering activities,

Table 8-2
Required Courses for Specialization in Environmental Process Engineering

Physico/chemical Unit Operations I
- Precipitation
- Coagulation and flocculation
- Gravity sedimentation, thickening, and flotation
- Filtration (porous media and cake)
- Adsorption
- Desorption/leaching
- Ion Exchange
- Mixing/blending
- Gas transfer/stripping

Physico/chemical Unit Operations II
- Oxidation/reduction
- Disinfection
- Membrane operations
- Centrifugal operations
- Electrostatic operations
- Solidification/stabilization
- Chemical destruction
- Thermal processes
- Supercritical fluid systems

Process and Facility Design (Each module is 1 sem. cr. hr.)
- Required Module on Principles of Design
  - Strategy of process engineering
  - Quantitative and nonquantitative decision making
  - Optimization
  - Project organization and management
  - Contracts and specifications
- Elective Modules (Must take two)
  - Water treatment
  - Wastewater treatment
  - Air pollution control
  - Site remediation
  - Hazardous waste treatment

ONE OF THE FOLLOWING MUST BE TAKEN

Biochemical Operations	Bioremediation	Air Pollution Control Engineering
Suspended growth	Biodegradation	Aerosol mechanics
Modeling	Bioavailability	Industrial ventilation
Application	Soil/microbe interactions	Particulate control systems
Attached growth	In situ remediation	Gaseous control systems
Modeling	Soil slurry bioreactors	Physical
Application	Treatability & scale up	Chemical
		Biochemical

two courses on the subject are required of all students in this area. It should be emphasized that the unit operations included are not limited to those in water and wastewater treatment. Rather, operations for air pollution control and hazardous waste treatment are included as well. The students are also required to take a course in process and facility design. This course represents a large departure from the way we have handled our capstone design course in the past because it will contain several modules worth one credit hour each. All students will be required to take the module on the principles of design where they will learn how to organize projects, deal with contracts and specifications, and conceive of appropriate processes from the unit operations they have learned about. This module will be completed during the first third of the semester. During the remainder of the semester they must take at least two additional modules in specific design areas. These modules will be interrelated and will involve several of the faculty. In addition, students must choose one additional course from a list of three, as shown in the table. The choice of that course will depend on the whether the student wants to emphasize water/wastewater treatment, hazardous waste treatment/site remediation, or air pollution control. Elective courses include things like a unit operations laboratory, hazardous waste management, one of the required courses from another specialty area, or one or more of the optional courses in Table 8-2. Students preparing a thesis are required to take 24 semester credit hours of course work, and thus their choices will be limited. Nonthesis students must take 30 hours of formal course work in addition to a special project; consequently, they have a greater opportunity to pursue electives for greater breadth.

Environmental chemistry has been an important area of specialization in our department for many years and is popular with our science students, although engineers often pursue it as well. As indicated in Table 8-3, our course offerings are focused on the fate of pollutants in the environment and provide an excellent foundation upon which to build. Furthermore, the first two courses in the table are very popular electives for students in both the environmental process engineering and contaminant fate and transport areas. A major goal of the lab course is to help the student understand and appreciate all that is involved in the generation and interpretation of environmental data. Thus, it is very important to practice, regardless of whether the student ever works at the lab bench again. Like courses that have been started at many universities in recent years, the organic chemistry course focuses on the reactivity of chemicals in the environment rather than on the synthesis reactions common to classical organic chemistry courses. We are currently experimenting with sending incoming students a handout containing information on basic organic chemistry fundamentals and nomenclature that is necessary for entry into this

Table 8-3
Required Courses for Specialization in Environmental Chemistry

Environmental Chemistry Laboratory I
- Experimental design
- Statistical analysis
- Quality assurance/control
- Acid/base chemistry
- Oxidation/reduction reactions
- Sampling
- Analytical techniques

Environmental Organic Chemistry
- Thermodynamics
- Kinetics
- Macroscopic transport
- Phase transfer
- Hydrolysis
- Oxidation/reduction reactions
- Structure-activity relationships
- Photochemistry

Advanced Topics in Environmental Chemistry
- Chemodynamics
- Speciation
- Complexation
- Sorption
- Bioaccumulation
- Multimedia, multispecies modeling
- Acid/base chemistry
- Oxidation/reduction reactions

course as well as the environmental biology course in the core. We hope that will help students with a weak chemistry background be better prepared. Environmental chemistry students often take elective courses in advanced instrumentation, some of which are taught jointly with the Department of Environmental Toxicology, one of our sister departments in the School of the Environment. They also take courses in contaminant fate and transport, illustrating the close linkage between the two areas.

The courses and required knowledge for the contaminant fate and transport area are shown in Table 8-4. Two courses focus specifically on fate and transport in all media, while the third gives the students the tools for using the knowledge acquired in the other two courses to make decisions about environmental risk. Our other sister department in the School of the Environment is Geology, which has a strong emphasis on geohydrology, and faculty hold joint appointments in both departments. Consequently, a number of elective courses are available in Geology, including groundwater modeling, subsurface remediation modeling, and geochemistry. Furthermore, because all students must take environmental biology, students in this area may also elect to take biodegradation/bioremediation, which will strengthen their abilities to understand and forecast natural attenuation. Like most programs, we have experienced significant growth in this important area in the past few years. With our current course offerings we feel that students from diverse backgrounds can be prepared to functional successfully in this important area.

Table 8-4
Required Courses for Specialization in Contaminant Fate and Transport

Flow and Reactive Transport

- Ground water modeling
- Surface water modeling
- Advection-dispersion equation with:
  - Chemical reaction
  - Biochemical reaction
  - Radioactive decay

Air Pollution Meteorology

- Micrometeorology
- Plume rise modeling
- Atmospheric diffusion
- Deposition and washout of pollutants
- Atmospheric chemistry
- Air quality planning

Environmental Risk Assessment

- Risk assessment process
- Contaminant release assessment
- Environmental transport modeling
- Exposure assessment
- Human health effects assessment
- Ecological effects assessment
- Stochastic analysis

The nuclear environmental engineering area, described in Table 8-5, has been an important part of our department for fifteen years and attracts a large number of students. Although relatively few environmental engineering programs offer such an area, the knowledge and skills imparted through it are very important to a broad constituency, and thus it is important to include them in the knowledge base for environmental engineering. While there is some overlap between the course on radioactive waste management and the unit operations courses, it was considered to be small enough and the problems encountered in this area unique enough to justify a separate course. The course in environmental risk assessment, which is also required in the contaminant fate and transport area, was originally developed for the nuclear environmental area before risk assessment became an accepted tool for analysis of other environmental problems. It now is an important elective for the areas in which it is not required. Students specializing in this area commonly take electives from all of the other areas, again demonstrating the need for the integration of skills across the breadth of environmental engineering.

The final specialty area in our department, waste management, is our newest and is still under development. Consequently, I have not prepared a table of the required courses and the knowledge imparted. However, the risk assessment course is likely to be one of them. In addition, we are considering development of a broad-based graduate level course to survey the technical aspects of the waste management area. Finally, we anticipate that a course on environmental policy taught in another department will be required. Electives will include courses in solid waste and hazardous waste management.

Table 8-5
Required Courses for Specialization in Nuclear Environmental Engineering

Environmental Radiation Protection

- Radioactivity
- Radiation interactions in matter
- Radiation dosimetry
- Radiation shielding
- Radioactive decay
- Human health effects of radiation

Ionizing Radiation Detection and Measurements Laboratory

- Counting statistics
- Gamma-ray spectroscopy
- Alpha spectroscopy
- Radiation interactions in matter
- Radiation dosimetry
- Radiation shielding

Radioactive Waste Management

- Isotope production/separation
- Nuclear fuel cycle
- Advanced dosimetry and shielding
- Regulations
- Waste classification and treatment
- Exposure pathways

Environmental Risk Assessment

- Risk assessment process
- Contaminant release assessment
- Environmental transport modeling
- Exposure assessment
- Human health effects assessment
- Ecological effects assessment
- Stochastic analysis

When reviewing the knowledge base represented by our core courses and the various specialty areas, one will find many omissions. There are several reasons for that. First, the items presented represent our assessment of minimum competency in the areas. Many other skills will be attained through elective courses, both in our department and in others, that are too numerous to mention here. Second, our assessment represents our backgrounds, biases, and limitations. One of the strengths of environmental engineering education in the United States and Canada is that no single body has dictated what we should be. This has given each university the opportunity to develop programs that reflect its strengths, thereby providing students with a broad diversity of programs from which to choose. As long as we all try to build our programs on a sound foundation of fundamentals and prepare our students for lifelong learning, the mix of students that we graduate will collectively have the ability to creatively solve the new problems that will confront us. The wisdom of this approach has been proven by the manner in which our profession has been able to respond to problems that were not anticipated even twenty years ago. Since none of us is prescient, we can't know what will arise in the future, and thus we must continue to rely on creative problem solving based on sound fundamental principles and our educational programs must prepare our graduates for that.

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The Environmental Engineering and Science Program at Stanford University

Perry McCarty

When I started teaching in the environmental engineering field in 1958, the available textbooks based design of most treatment units on simple rules of thumb. Settling tanks were based on so many cubic feet per capita, or so many square feet per gallon of water, etc. There was very little basic understanding given of the processes involved. As a student, I found it quite difficult because the empirical formulas had little fundamental about them that provided understanding of the processes involved. A design formula for a trickling filter was entirely different from that for activated sludge treatment, which was different than that for a lagoon, which was different from that for a digester, and so on. However, a trend toward the present was just beginning and researchers were trying to understand processes in a much more basic way so that they could be applied more generally for the wide variety of problems with industrial wastes that were just emerging.

I remember teaching at that time, trying to introduce some of the newer concepts in the design of an activated sludge plant, so I asked the students to apply mass balance, Monod kinetics, and solids retention time. Going through all this theory, it turned out that the appropriate detention time for an activated sludge plant for municipal wastewater treatment was six hours. The students then looked this up in their old textbook, which said to design an activated sludge aeration tank with six hours detention time. A common response then was, "what do we need all this theory for when the textbook says to use six hours?" And, of course, they were right. This is quite appropriate when we want a conservative design for an activated sludge plant to treat municipal wastewater. Six hours was based upon a lot of empirical experience from the past and was found to work in this case. But how about the newer problems with industrial wastewaters that are not like municipal wastewaters? Engineers who tried six hours usually found it did not work. To apply design to industrial wastewaters a good fundamental understanding was needed as each waste is different and the empirical approach is of little value. The time was approaching where a more fundamental understanding was required. And it came fast. By the time of Earth Day and the environmental revolution, we found a demand for knowledge that we were just beginning to acquire. We found ourselves way beyond our background of experience. We couldn't draw upon the rules of thumb anymore. And that's when the need for sound fundamentals came into the picture, when we really needed them.

We know today that we must ground students in process fundamentals. By providing a good background in the fundamentals, we are preparing the future professionals with the ability for lifelong learning. This is most important.

While our knowledge and application skills have grown, so also have grown in complexity the problems that we are asked to address. From the interest in pollution prevention and waste minimization, the question is raised: "Where do we fit into this? Do we fit in at all? Is there some niche for us?"

Should we try to develop skills in our students to address such problems? Another example — global warming. Do we fit in with this topic at all? Ozone depletion, deforestation, species diversity and extinction, resource depletion, material reuse, these are other areas of environmental importance. Does teaching our students how to recycle plastic and glass make sense? We certainly heard about the globalization of the environment, and continue to hear about the big one of population growth and explosion. Can we participate in the solution to these problems in a meaningful way? These are major environmental problems, and certainly we will not solve them all, but I think the question is: Is there a place for us, and how might we best participate? I cannot provide the answer to these questions, but they deserve our active consideration. I would like to turn to areas where we have been successful and will continue to be so, such as water supply and water pollution control. First, I would like to suggest to all new faculty, and perhaps some of the older ones as well, that from time to time we should review the series of documents that have come from conferences like this in the past. I have here a copy from the sixth conference, which was held five years ago at Oregon State University. The title was something like that of this one — "Environmental Engineering Education in the Year 2000." If we look back to the trends and views that have been consistent we find several items. I'd just like to quote from a couple of such items. One is from a committee reporting from the professors' side of things, a committee chaired by Dick Luthy. They addressed future concerns in environmental graduate education. They said, "A lesson from the past is that graduates must be prepared for change," and, "as it is not possible to predict with certainty what skills will be needed in the future, students must be educated in the fundamental fields so that they will be equipped to deal with change. This requires training in the sciences as well as engineering, and it requires development of communication skills." Also, "These traits may be fostered by faculty with diverse abilities, and by faculty who appreciate this diversity." Now, that's a tall order. "The educational atmosphere should include a mix of natural sciences and engineering, and combine engineering with the humanities and social sciences. All of these issues are still relevant today." That was five years ago. Well, I'd say all of these issues are still relevant today.

At that conference, Jerry Schwartz with Doug Parsons gave a view from the consultants side. "There are some common threads that I believe should permeate our educational process. First and foremost is the need for good science and engineering fundamentals." And then sciences of importance were listed, "chemistry, biology, and transport phenomena are essential. Better grounding in theoretical fundamentals will carry you through a lifetime of environmental engineering practice, while the design of secondary clarifiers may have limited application in the next century." Now, I do not believe we should discontinue the design of secondary clarifiers, but I think the point is that fundamentals are clearly important in graduate education.

Another quote from Schwartz is, "If I could choose but one attribute that I would like to see in the new graduates, it is the ability to write — to communicate. The young engineer who can express him or herself well will usually rise to the top in practice." We keep hearing this; obviously communication skills are most important.

At the sixth conference they also referenced the fourth conference, which was in 1980, sixteen years ago. "The view taken at the fourth conference was that these and the broader areas carry an implied need for diversity and excellence. Because of the size of most programs, the argument was taken for encouraging a diversity of programs, each examining its own strength in light of societal needs, and striving to provide the highest quality of education possible. Programs should not be encouraged to look alike, but rather should define their own unique qualities and build strength upon this uniqueness. Curriculum content is not the determining factor in achieving excellence." Schwartz later stated "My purpose in describing these broad categories is to impress upon you the need for diversity. There is no one curriculum that would satisfy all our needs."

It is important that we remember the above quotes when we address our own problems. It is also important that we do not consider programs as something to copy, but something to consider when thinking about possible changes in your own programs, changes that might be appropriate for your own institutions.

There is clearly a need for diversity among us. Concerning the question of whether or not we should change to meet the growing needs, I cannot say whether we should or not. But certainly some of us will experiment, some of us will try different approaches and will attempt to address new problems. In this way we might find niches where we fit in, and in this manner we will progress and we will learn from each other's experiences. That is one great benefit we gain from a diversity of programs rather than from a group of programs that all look basically the same.

Now, switching from these general comments to a few about Stanford University. We have attempted over the years to build primarily on the strengths that we have available. We have an Environmental and Water Studies Program, and within that there are two degree programs — one in Environmental Engineering Science, which has seven faculty, and one in Environmental Fluid Mechanics and Hydrology, which has eight faculty. We encourage students to participate in both programs because we have strength in both areas. Also, in the School of Earth Sciences there is a Department of Geology and Environmental Sciences with a strong emphasis in groundwater, groundwater modeling, and petroleum engineering. We built our program upon that strength as well. This permits us to offer a wide range of possibilities for the M.S. program in Environmental Engineering and Science, giving us much diversity. Within our seven faculty members we have a diversity as well which we feel is important. Our Faculty have undergraduate degrees in chemistry, microbiology, electrical engineering, chemical engineering, engineering science, and only two have civil engineering backgrounds. We also like to encourage a diversity within our students, some have backgrounds in science, such as chemistry and microbiology. However, we only select the scientists who have sufficient quantitative skills to study effectively in a problem-oriented program. Engineers with any background are acceptable as long as they are bright and have the desired goals in mind.

But generally, what we like to admit are M.S. students with broad and different backgrounds, including different skills, different university credentials, and different career goals. So how can a program accept students with different backgrounds and prepare them for different goals? We attempt to do that by maintaining a curriculum that has many electives, that is, one with much choice. But within those choices, we have defined a core curriculum that represents, in effort, about 40% of the M.S. degrees and emphasizes the fundamentals. The fundamentals are very important. Now, within that, we have about fourteen different courses, of which the students will select a minimum of six. Here, we emphasize chemistry, biology and movement and fate of contaminants, as well as some of the engineering principles of mass and energy conservation, mass transfer and reaction kinetics.

We have another 30%, or one-third of the M.S. program that represents breadth electives. This includes a long list of courses that can help fill in the technical backgrounds of students and prepare them, depending on their interests, with more chemistry or microbiology, more fluid mechanics and hydrology, groundwater transport, or computer skills. Other courses emphasize planning and management options. And then, for the remainder of the program, students either take more of the core courses or more of the breadth electives.

Other very important electives in the breadth area are two courses in communication skills. We encourage students to take these courses as electives. Now they do not all do that, but we keep encouraging them to do so by telling them the importance of these subjects.

Other courses that we include in the core or breadth areas are four laboratory courses. We had required laboratory courses in the past. But over the last few years when we have a very large student enrollment, we found we did not have the resources to provide lab courses for all the students. Thus, now we offer the laboratory courses as electives. I think we have a feeling that we should really require some laboratory work of all students. Without that, they start losing a hands-on feel for environmental problems. I think laboratory courses are very important, and somehow we need to figure out how to return to requiring some laboratory work of all M.S. students.

So, what we have in general is a broad curriculum, one that offers much selection by the students, depending upon their background and their career goals. Nevertheless, whatever we offer, the courses emphasize fundamentals. We do not offer survey courses in many subjects. While the students generally like them because they seem relevant at the moment, they generally do not stress fundamentals that are long lasting.

There is much we would like to teach students, but they can only learn so much in one year. Whatever they learn in that short period should primarily be grounded in fundamentals upon which they can build over a lifetime of learning. That is the best way we feel to prepare students for the future.

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SECTION 3

Skills and Attributes Required of the Environmental Engineer: Practitioners' Perceptions

Skills and Attributes Required of the Environmental Engineer: A Practitioner's View

Robert C. Marini

Education of today's engineers is an extremely important issue, particularly when it comes to making sure that we are cultivating the skills necessary to take graduates successfully into the 21st century.

This presentation focuses on the skills and attributes required of the environmental engineer from a practitioner's perspective. Looking back over the past 40 years and trying to look forward over the next 20, there are *nine* factors identified — *three historic, three current, and three emerging* — which have been and will continue to be criticial to the success of the environmental engineering professional. I firmly believe that a solid technical foundation is of absolute importance. I also believe — from a practitioner's standpoint in today's marketplace — that educational institutions and private employers of engineers will be successful in direct proportion to their ability to understand and develop a challenging combination of technical credentials and real-world skills in the new generation of environmental engineers.

Before I begin, however, I'd like to provide a thumbnail sketch of my company. Camp Dresser & McKee is one of the world's leading environmental engineering firms, with 2,500 people working in more than 90 offices worldwide. Headquartered in Cambridge, Massachusetts, our staff of engineers, scientists, and consultants work on projects on just about every continent on earth, in countries including Australia, China, Egypt, Singapore, Israel, Brazil, Bangladesh, the former Soviet Republics, Germany, and, of course, the United States.

CDM began as a partnership in a tiny office in Boston back in 1947, and it has grown to its industry leadership stature for several reasons; one of which is that CDM has always stressed the importance of competent, talented, and energetic people as our most important resource.

My Entry Into the Environmental Engineering Profession

Let me begin by noting that the environmental engineering profession today barely resembles the profession it was when I accepted my first full-time engineering position in 1954. Back then a bachelor's degree was the necessary entry card. Today, it takes a graduate degree to open many doors of the environmental engineering profession, but my undergraduate training was sufficient preparation for me to enter the workforce.

In 1949, as a freshman civil engineering major at Northeastern University in Boston, I had already set my sights on a career in construction engineering. While I was enrolled in the traditional engineering curriculum, with heavy emphasis on civil and sanitary engineering courses, I believe the single most valuable component of my undergraduate career was the cooperative education program, which Northeastern was one of the leaders in implementing.

I began working as a co-op with a civil engineering firm that, ironically, is a major player today in the environmental field and a chief competitor of CDM's. Until my graduation in 1954, I drafted designs, performed calculations, conducted surveys, and contributed to a number of project teams working mainly on water and wastewater systems and treatment plants.

As I reflect on those years, which were some of the most formative and significant years of my life, my technical training was rigorous and extremely important. I must add that it is not necessarily the technical engineering experience that stands out. Instead, I remember the people, the senior engineers who taught me during my tenure as a co-op, and the skills they helped me develop. I honed my interpersonal skills, my ability to listen to and understand other engineers' perspectives and concerns, and my ability to function effectively as part of a team.

CDM continues today as an active supporter and participant in cooperative education programs with universities across the country.

My graduate-level training at Harvard broadened my knowlege in two ways. First, it expanded my technical knowledge of bacteriology; parasitology; water quality; organic, inorganic, and physical chemistry; and hydraulics. It also served to expose me to an international student body and a far more global approach to environmental issues and answers.

What I Look for in New Hires

Historic Factors — Credentials (Figure 10-1)

In the 1950s, of course, employers were not necessarily looking for graduates with a lot of hands-on experience on their resumes. The job market in the U.S. was healthy, the economy was strong and growing, and employers counted on technical aptitude and credentials to select their next employees: a degree from a good school, a solid academic record, a careful course of study, and strong letters of recommendation from professors.

Figure 10-1
Historic Factors — Credentials

- Respected Academic Institution
- Academic Record
- Professor Recommendations

Current Factors — Experience & Skills (Figure 10-2)

Without a doubt, employers — my own firm included — still seek a degree from a respected school, a rigorous course of study, and a solid grade point average. In addition to a proven academic record, we also require well-developed and proven skills in teamwork, critical thinking, communication, problem-solving, and interpersonal relations. These tools augment students' technical foundations and produce graduates who possess the necessary confidence, adaptability, and the ability to deal with rapid change and with the "information overload" that is already upon us in this decade and that will continue into the 21st century.

Figure 10-2
Current Factors — Experience and Skills

- Practical Experience
- Teamwork Skills
- Communications Skills

We look for graduates — bachelor's degree and master's level — who appreciate that today's firms must compete globally as well as locally, who understand cultural differences, and who are possibly proficient in foreign languages. We want our new recruits to possess integrity, can-do attitudes, and an ability to integrate knowledge and skills. We need a more diverse work force, by technical discipline, gender, and ethnicity, to better manage complex projects and multinational clients. Ideally, we want graduates with experience. Required qualifications are no longer purely credential-based; instead, they have become a distinct combination of credentials and skills.

In short, we need such skills-based, diverse graduates because our clients increasingly demand such talent on their projects.

But I am speaking from my perspective as CEO of a service company, a firm that sells its technical and management skills, not a consumer product. Like all consulting businesses, CDM is and will always be about people, so you can probably understand why we place a high premium on the interactive, people-oriented skills I mentioned.

I will always support an increasingly challenging technical curriculum at the academic level. But equally important, I also support development in social capabilities, including the financial skills essential in project management and effective verbal and written communications skills. Again, as a practitioner, I find that much of the latter development is left to on-the-job training, which is often difficult and very costly for a company to develop and implement. I am not recommending that development of these skills supercede technical training; however, I encourage looking at ways to implement skills training with university programs in addition to maintaining superior academic standards.

Looking back over the years — and also at my company's workforce today — I am extremely proud of CDM's successes in attracting well-rounded talent. It's no accident that the level of relevant work experience possessed by our new graduate hires is unprecedented today. We do seek experienced, articulate graduating candidates. Providing students with meaningful work experience and essential interpersonal skills during their school years benefits both the students and any firm they join after graduating.

Recommended Additions/Deletions to Engineering Graduate Programs

So what can graduate programs do to cultivate the multi-faceted skills required of today's engineer? I would like to see the development of more cross-unit curriculum, one that integrates components from the engineering, social sciences, and business schools. This may require extending undergraduate progams to five years or adding a year to graduate programs to cover the necessary areas, even though one trend of late has focused on shaving time off of the traditional engineering degree programs. I strongly believe that you cannot simply equip students with the nessessary scientific formulas and algorithms and consider them prepared to effectively compete in today's marketplace. Nor do I recommend reducing time spent on teaching superior technical skills. While I firmly support a cross-unit curriculum, I believe that these interdisciplinary skills are in addition to technical skills and by no means in place of them.

The Massachusetts Institute of Technology has designed a Masters of Engineering program that I consider to be a model for all universities in bridging the classroom-project gap. Designed as a nine-month, eight-course program, it incorporates six strictly technical development courses, rounded out with a project-focused course and a professional training course. This past year, the students in the program used the Massachusetts Military Reservation groundwater plume clean-up project as the basis for a host of masters-level projects, including team-focused problem solving and public presentation skills. The professional training course focuses on essential professional skills, including risk management, project management, and basic finance skills.

Programs such as this help a student develop in practical, proven ways above and beyond academic theory. I am pleased to report that MIT's program has received inquiries from universities across the country. I hope we see more of this cross-training approach.

Essential Skills for the Future

Emerging Skills — Eclectic (Figure 10-3)

Today we operate in a truly global market. While I believe our colleges and universities are producing technically competent engineers, I agree (with other speakers) that we must continually strive for superior standards. And I will again stress the genuine need for 'big-picture' skills. With political and social pressures, financial constraints, and regulatory compliance driving many environmental efforts, engineers entering the workforce need to have solid technical training, as well as interpersonal, financial, political, and cross-cultural skills. Seldom do engineers at Camp Dresser & McKee sit isolated in an office designing a facility. In reality, they are working as vital members of a project team, assisting a client that is seeking approval from a finance board, providing explanations of extremely technical projects to concerned citizens at a public meeting, negotiating regulatory waivers, or assisting labor/management relations in a public/private partnership effort. Their technical skills are top-notch — they have been taught well at the university level, and our own technical training programs and superb project experience are building on those skills. And their skills — technical and interdisciplinary — are called upon *daily* to get the job done.

Figure 10-3
Emerging Factors — Eclectic

- Entrepreneurship
- Ability to Create Change
- Vision of the World from Client Perspective

I know there has been some dialogue about the value of graduate students writing a thesis. A thesis can be of value because it exposes students to the intensive report-writing, thesis-justification process that consulting engineers are often called upon to do. My concern is that it frequently entails substantial amounts of time devoted to literature research. Generally, no original research is performed, leading me to question if this process develops the maximum number of skills relative to the amount of time it consumes. I believe more meaningful skills could be developed by devoting that time to interdisciplinary skills development, team project management, or projects that embrace a cross-cultural approach or address problems that constrain today's projects, such as siting, funding, and population growth. In order to develop these skills in addition to the vast amount of required technical training, we need to ensure the best use of our most limited resource — time.

As academia evaluates its success in honing engineering students' analytical skills, training in real-world skills also demands attention. To foster the global-market perspective necessary to succeed in the 21st century, it is essential to teach engineering students the societal context in which they will work.

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Skills and Attributes Required of the Environmental Engineer: An Industrial View

John B. Wilkinson

History

In 1991 Manhattan College celebrated 50 years of environmental education. Over that period, the needs in curricula have changed dramatically. These needs in "environmental engineering" were largely driven by the societal concerns of the day as reflected in environmental legislation. There were few regulations in the early, mid-part of this century and programs such as Manhattan's emphasized sanitary engineering. This evolved through time to include industrial issues but still with a wastewater emphasis. Indeed, in 1970 I graduated with an M.S. in Environmental Engineering from Manhattan and my skill set was ideal for the industrial environmental challenges I faced. Manhattan had provided an education with a strong emphasis on wastewater unit operations, and I was able to contribute directly throughout the 1970s as Exxon upgraded existing and built new wastewater units in the United States and around the world.

However, throughout the 1970s and 1980s environmental concerns became more diverse and legislation mounted to address these concerns (Figure 11-1).

Today's Environmental Profession

The environmental profession today covers a broad range of issues. Figure 11-2 provides a snapshot of the ever-evolving challenges we face. While still needing to keep our waterways clean, an industrial environmental professional may be involved in such diverse activities as emission source control, region acid rain, or global warming. Indeed, over the course of my career I have been involved in most of the areas noted in Figure 11-2.

Starting from the proposition that the environmental profession needs to span the activities in Figure 11-2, we'll see how this translates into skills and attributes for several sectors of our profession.

Industry

An environmental engineer in an industrial setting needs to be capable of understanding a broad spectrum of technical issues. The educational emphasis should be on basic skills. A deep understanding of chemistry, biology, and processes is needed — industrial processes to work on waste minimization, treatment processes to treat remaining emissions, mass transport processes to understand ultimate sources and sinks as pollutants are transformed, and atmospheric processes dealing with global, regional, and urban issues. Underpinning all of this is an emphasis on risk-based decision making.

The industrial environmental engineer is not a deep specialist in a particular technology (although we do look for some level of specialization in a campus hire so that the individual can quickly contribute). Rather, that person understands the issues particular to their industry, and uses a strong technical foundation to properly represent these issues to deeper technology experts (consultants) hired for specific tasks.

Consultants

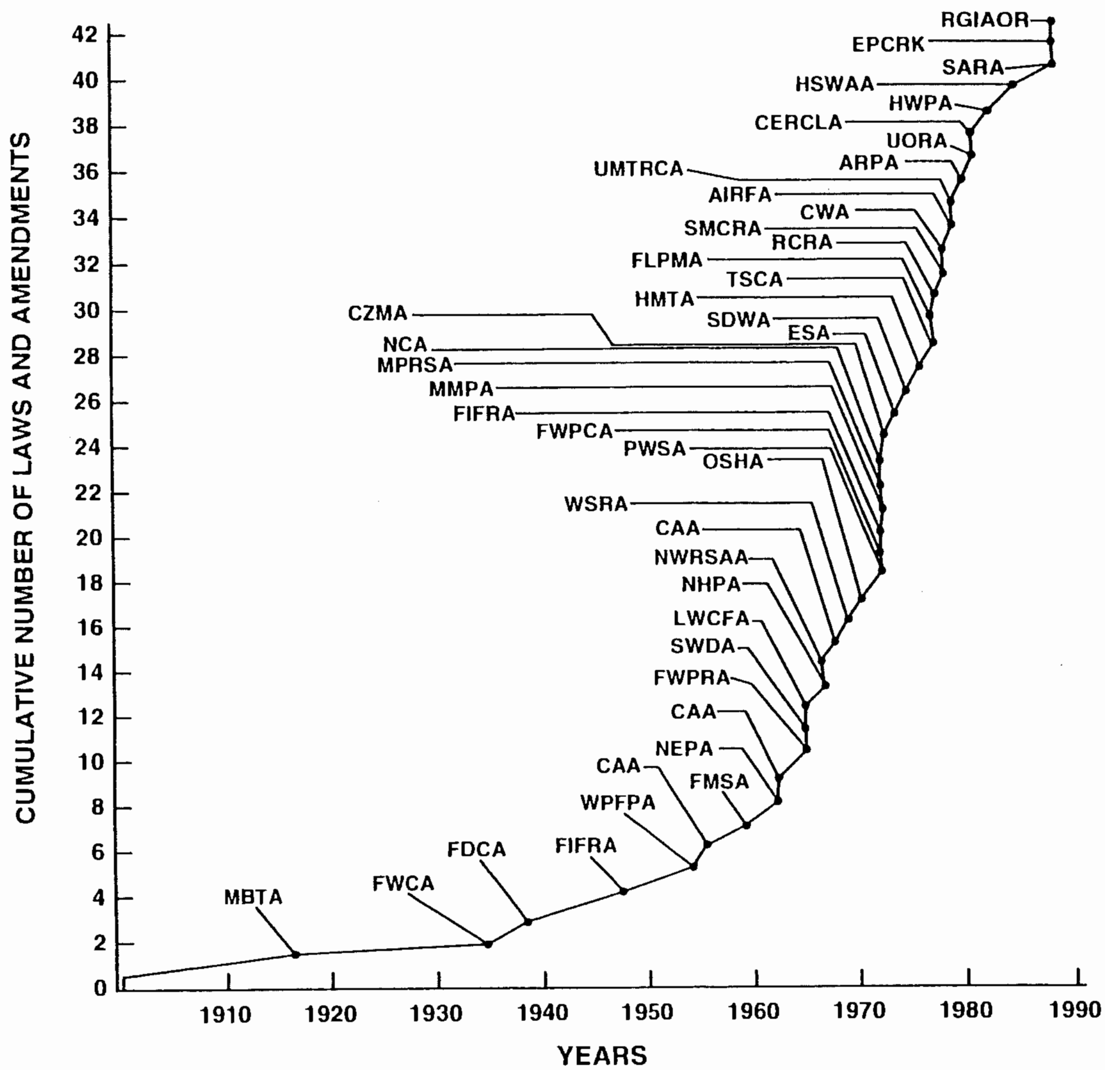
While the industrial person will broadly cover the areas in Figure 11-2, the consulting community in general is populated by individuals who are expert in more focused technologies and who, in aggregate, address all these areas.

I would expect engineers in this category to have sufficient coverage in basic skills to underpin their specialty, and to facilitate interaction with other experts, industrial clients, and regulators.

Regulators

Because of the broad range of pollutant sources and potential solutions they must address, I would suggest

Figure 11-1
Federal Environmental Legislative Power Curve



that the regulatory community needs to be a mix of the skills and attributes found in industrial and consulting settings.

Overall Picture

In my opinion, the overall picture is one of a continuum (Figure 11-3). There are probably few people with 100% of the attributes at either end of the spectrum. For instance, an industrial person with a broad basic technical founding is also likely to have some level of specialization. Similarly, consulting firms need some less specialized technical generalists to effectively deal with their customers.

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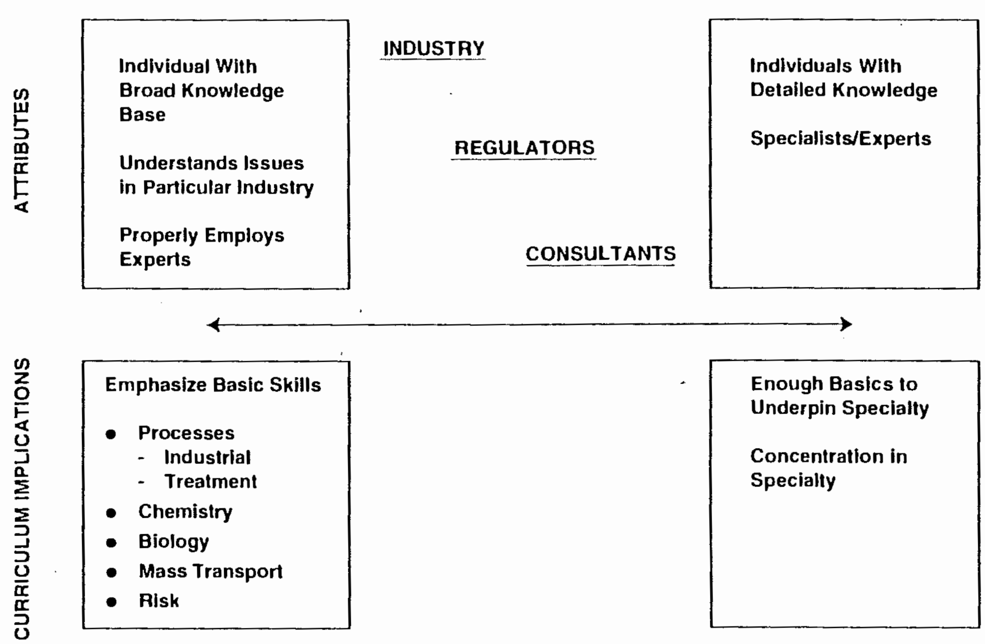
Figure 11-2
Evolving Broad Range of Environmental Professional Challenges

Global	• **Tropospheric Ozone** • **CO_2 Greenhouse**
Trans Border/Regional	• **Acid Rain**
Emission Reduction/Reuse	• **Solid/Hazardous Waste** • **Wastewater** • **Air Emissions**
Treatment/Disposal	• **Solid Waste** • **Wastewater** • **Air Emissions**
Clean Products	• **Transportation Fuels** • **New Refrigerants (replace Freon)** • **New Packaging** - **Replace Styrofoam with non-CFC** - **Biodegradable** • **Etc.**
Site Remediation	• **Treat Contaminated Soil and Groundwater**
Sustainable/Clean Energy	• **Alternative Fuels** • **Synthetics** • **Renewable Resources**
Hazard and Risk Assessments/Minimization	• **Sound Science Driving Decisions**

Figure 11-3
Environmental Profession Continuum



SECTION 4

Role of Practitioners in Education

Environmental Engineering Education and Practice: An Industrial Perspective

Hugh J. Campbell, Jr.

Introduction

There is something in the basic makeup of engineers that drives them to tinker, to poke at a project, a theory, or course of action to see how it can be better. If we tweak this valve, if we raise the pressure, if we lower the temperature, if we lengthen the residence time, if we lower the charge, maybe we can improve the outcome. This drive for excellence has been at the core of the tremendous scientific and technological advances society has come to expect and to rely on. But more and more this bias toward continuous improvement seems to be turned inward to challenge not only what engineers do, but how they are trained to do it. Professional journals and magazines are filled with articles on what is wrong, right, or indifferent about engineering education; what needs to be different and why (Pohland and Anderson 1996; Baillod 1986; Williamson and Miller 1991; NRC 1995; Luthy et al. 1992). These discussions are typically thoughtful and informed; not surprisingly, they are provoking an increasingly lively and useful dialogue between the purveyors of engineering education (colleges, universities, and their faculties) and the consumers of the educational product (industry, for one). No place is the need for such dialogue more acute than it is in the area of environmental engineering, primarily because, aside from the fundamental laws and principles, little else in this area is as it was 25 or 30 years ago. Industrial practitioners simply don't do their jobs the same way, and the jobs themselves have broadened beyond what was conceivable 25 or 30 years ago. These changes and their ramifications for education are driven primarily by two factors integral to the current milieu within which industry operates: the emergence of environmental consciousness and global competition.

The eruption of environmental consciousness or awareness two or three decades ago forced industry to reevaluate its operating practices to fully understand and minimize the environmental effects. The environment could no longer be viewed as a nebulous entity somewhere off the edge of the process diagram with an infinite capacity to absorb waste and emissions without damage. New regulations spurred a reordering of priorities. Environmental engineers (who, at that point, were probably called sanitary or civil engineers) found themselves scrambling to ensure that their companies operated without harm or foul to the surrounding communities and in compliance with discharge levels that were constantly being ratcheted downward. Most were somewhat prepared to function in these circumstances; that is, what they had learned in traditional engineering courses could be applied to at least some of the technical aspects of the challenge. Most weren't prepared, however, for the broad elaboration of their roles, particularly in relation to regulatory matters, the surrounding communities, environmental activists, and the media. These new responsibilities required a set of nontraditional and, for the most part, nontechnical skills that have not typically been emphasized in the standard engineering curriculum.

The second factor, global competition, challenged the notion of American technological superiority and mandated more cost-effective and efficient approaches to everything related to manufacturing, including environmental protection. Industry was (and still is) competing on a whole new playing field (the world as opposed to only the U.S.) where few of the rules and team rosters were the same. U.S. industry experienced a tremendous culture shock that forced it to scrutinize every aspect of its operations. It quickly became clear that to be successful the newly defined "global" corporations needed technical personnel who were not only on the cutting edge technologically, but who could work productively in a multinational, multicultural environment.

In other words, environmental engineers of the present and the future must be clones of Iam A. Techie and Alan Alda. They must master all of the traditional technical fundamentals and several new ones, and they must branch out beyond the "technical" to become more "holistic" — sort of "communicative techies." They must understand the business and societal trends that drive their industry; they must be prepared to make reliable, cost-effective technical responses; and they must be able to communicate those responses to regulators, communities, environmental activists, and the media in understandable terms. Furthermore, the different stakes and interests of these constituencies can and usually do require the ability to communicate at several levels and to be sensitive to a variety of perspectives. The challenge for educational planners in all of this is how to maintain and strengthen the traditional engineering education, while stretching to accommodate the new, nontraditional needs.

Traditional Scientific and Engineering Fundamentals

Environmental engineering has traditionally been housed within Civil Engineering Departments, a logical and generally satisfactory pairing, given the past focus. The standard environmental (or sanitary) engineering curriculum emphasized water and particularly biotreatment; in other words, end-of-the pipe treatment before releasing effluent to surface water. (It's astounding to note, looking back from today's perspective, the dearth of courses relating to other media.) This was fine thirty years ago, but many of the basic assumptions and modes of operation that supported this curriculum have changed. In our current circumstances:

- Releases to the environment are stringently regulated as the result of several major legislative and regulatory initiatives.
- Waste treatment is increasingly turning to waste prevention and has moved back up the pipe and actually into the process.
- Risk assessment is gaining acceptability and methods of evaluating and predicting the fate and effect of chemicals in the environment are now highly sophisticated.
- Costs are increasingly scrutinized, and cost-benefit analysis and issues of sustainability are playing a much greater role.
- Computer tools are widely used to assist and expedite environmental analyses.
- There are more complicated challenges that increase the need for creative and innovative thinking.

All of these changes have broad implications for the environmental engineering curriculum.

Environmental Policy, Legislation, and Regulation

Advances in public environmental policy, legislation, and regulation have affected industry at all levels. Environmental issues, which used to be the concern of a designated few within a corporation, are being integrated into all phases of producing and selling products. While it is totally appropriate that the protection of human health and the environment has become a top priority, the drive to accomplish this goal has spawned a tangled and occasionally counterproductive mass of regulations. Untangling this mass to ensure that his or her company achieves compliance yet remains competitive can occupy a major portion of an environmental engineering practitioner's time and mandates sufficient knowledge of the area. However, this is a dynamic area; it is constantly evolving as we work to simplify regulatory approaches. Thus, while it may not be possible to make each student a regulatory expert, it is essential to provide the underpinnings in three key areas: the regulations themselves, the practical application of the regulations, and the ethics of functioning in a highly regulated industry.

Regulations. Environmental regulations impact every facet of industry today. For example, the cost of regulatory compliance is a significant business expense; it can be the difference between profit and loss, making and not making a product. This deep integration means decision makers at many levels and with a variety of responsibilities within a company are involved with environmental issues. Therefore, even students who do not remain practicing environmental professionals throughout their careers will need a basic understanding of the strictures that these issues can impose. Being knowledgeable about the basic goals and drivers of public environmental policy, key legislative pieces, the overall structure of the regulations, and probable future direction will enable decision makers to feed these considerations into their goals and objectives. Academics must always remember that they are now preparing (and influencing) the engineers who will be making the decisions for industry in the not too distant future. Integrating regulatory understanding into the curriculum will, in the long run, extend the protection of our environment, while contributing to the health of American industry.

Application. Regulations are all too often written with a one-size-fits-all approach, but in applying them to a specific facility, the practicing engineer may soon discover site-specific, extenuating circumstances that render the prescribed approach technically inappropriate or economically infeasible. A practicing engineer must be able to: 1) accurately recognize these circumstances, and 2) justify a site-specific approach to the regulatory or legislative authority. This requires not only regulatory expertise but a firm grasp of basic science and engineering principles. An engineer who is petitioning for a regulatory variance must know beyond any reasonable doubt that the proposal provides the required level of protection, is technically feasible, and is cost-effective; that is, that it represents the best use of limited resources. The traditional engineering curriculum can provide the mastery required, particularly if students interested in environmental work are encouraged to add electives that enrich that curriculum. For example, in this case an engineer might utilize chemistry (environmental fate), chemical engineering (kinetics), geology (soil matrix), and costing procedures to develop an alternative proposal.

Ethics. Students need to understand up front that working in the environmental arena is a heavy responsibility. The stakes are extremely high; environmental engineers are involved in million-dollar decisions that can potentially affect the public's health and well-being. This intersection of high stakes and potentially conflicting interests can put technically trained personnel in situations that are not as well defined as their customary bailiwick, and students must have ethical standards to guide them. Intellectual integrity, respect for the law, and an appreciation of the unavoidable consequences of unethical and dishonest behavior must permeate the classroom. The ethic to do "what is right" within the constraints of a specific situation must prevail. Students should be aware that their chosen profession has a Code of Conduct and what that will mean to them as practitioners. Furthermore, requiring students to behave professionally in the classroom will expose them to relevant standards and facilitate their transition into the workplace.

Waste Prevention

The growth of environmental legislation and regulation has led to another dimension that affects what industry needs from environmental engineers: the main focus in waste management today is not treatment, but prevention. The press for waste prevention comes not only from regulators but from industry itself, which recognizes the overwhelming benefits of this approach both to the environment and to its bottom line. Waste prevention is central to many of industry's voluntary environmental initiatives. In 1988, the Chemical Manufacturers Association (CMA) introduced the Responsible Care® industry-wide initiative. The program comprises six codes of management practice, one of which is Pollution Prevention. Responsible Care is an obligation of membership in CMA, and member companies are participating in this effort to improve the industry's safety, health, and environmental performance. In another voluntary effort, DuPont has set a "goal of zero emissions" and mobilized its technical resources across the corporation to find ways to meet this challenge—primarily by engineering waste out of the chemical process. This means that in addition to dealing with the standard waste management issues, an environmental engineer at DuPont today must be able to work on teams with other engineering disciplines (chemical, mechanical, industrial, etc.) to evaluate waste prevention options. Here again, to work effectively in this environment, students will benefit from carefully focused technical electives in the basics of several engineering disciplines. Further, involving students in multidisciplinary teams to work on waste prevention projects would enhance students' training for the workplace by familiarizing them with the process, the other disciplines, and the issue, which will undoubtedly be a permanent one.

Risk Assessment, Fate, and Effect

The idea of evaluating the risk to determine an appropriate course of action is not particularly new. But it has achieved more prominence as our world has become more complicated and our choices more difficult. Using risk assessment to manage environmental problems (including remediation of contamination caused by past practices) is now very much a part of the environmental debate. It is not, as some have charged, a means to do nothing, but rather a valid method for providing protection where it is most needed and where it is most beneficial. It is rapidly becoming a major component of society's environmental approach. The federal Commission on Risk Assessment and Risk Management (an advisory group established by Congress) has recently issued its draft report, which calls for a holistic approach to risk management by placing problems into a broad context of public health and the environment. The chair of the panel, Gilbert Omenn, dean of the School of Public Health and Community Medicine at the University of Washington was quoted as saying, "We don't want paralysis by analysis. We want an effective and expeditious system for reducing risks and improving public health and the environment" (Chemical and Engineering News 1996). The panel recommends a six-step process that involves formulating the problem, analyzing the risk, defining options, making sound decisions, taking action on those decisions, and evaluating the effectiveness of the actions. Environmental engineers can play a key role at every stage of this process, but they must first understand the quantitative factors or methods for accurately assessing risk, and they must also be sensitive to the qualitative elements, which can be extremely powerful.

The two components in quantifying risk are hazard and exposure. As we engage in risk analyses, we must evaluate the fate, effect, and transport of a target substance. That is: 1) predict if and how the substance will breakdown in the environment and the by-products of that process; 2) establish the effect of the substance and its by-products on potential receptors; and 3) determine how and where the substance(s) will travel in the environment. This approach is widely used by industry (and society for that matter) to meet its growing need to better understand the fate and effect of water discharges, air emissions, waste disposal, and industrial products.

Establishing fate and effect generally includes often complex modeling, which requires computer skills, some chemistry and toxicology background, and an understanding of scientific transport mechanisms. Environmental engineers may not need to be modeling experts, but they do need enough understanding to assess the big picture; for example, to judge whether the inputs to a model will yield a reliable prediction and what the long-term effects of the decisions they make will be. More course offerings in risk assessment, fate modeling, toxicology, and life-cycle analysis would be useful. Statistics is another discipline frequently applied to risk and many other environmental areas. Understanding statistics, how they are developed, and their valid use would provide an important edge in this area. All of these courses would increase the readiness of the environmental engineering students to function in the industrial workplace.

Costs and Benefits

Economics has been a consideration for engineers in the past, but a number of cost-benefit issues have become very prominent in the environmental debate in recent years. The well-prepared engineer must have at least a general grasp of what they are and how they affect decision making. Industry is by and large seeking alternatives that provide sustainable environmental improvements. Take as an example the Superfund program, which has tended to emphasize costly, "Cadillac" cleanups. As a result, few sites have been cleaned up, and many have suggested that we cannot sustain this level of remedy and achieve the goals we have set. Might it not be better to clean up more sites to a level that is protective, albeit not to the Cadillac level; that is, might society not benefit more from an appropriate balance of cost and benefit. The concept of cost-benefit analysis has been a useful economic tool for some time, but it was catapulted to the front of environmental issues as part of the "regulatory reform" bills introduced to the 104th Congress. The bills, none of which passed, would have mandated that major new federal rulemakings, as well as existing rules, be subjected to cost-benefit analysis to demonstrate that the benefits of the rule justified the implementation costs; that the rule employed flexible reasonable alternatives; and that it adopted the least-cost alternative. These goals have been met in the past by a number of Executive Orders. This coupling of cost and benefit has been supported by a number of sectors and groups. Cost-benefit analysis methods combine engineering cost-estimating techniques and economists' valuation of benefits. They can help industry and regulators choose appropriate technologies, identify a range of benefits, and prioritize projects.

The balance of cost and benefit is the crucial aspect of this approach because it should enable us to make better use of limited resources. It is also important to note that for many, achieving this balance implies going beyond identifying the "cost-effective" option to identifying and considering the actual benefits that are part of the equation. This is a complex tool, which cannot be fully explained here. The point is that cost-benefit analysis and similar tools will be used more and more as we try to balance limited resources and sustainable operations in the future. To perform such analyses adequately, engineers must have a basic understanding of estimating, net present value calculations, and related economic evaluation components, which will be needed to calculate the cost of a number of environmental alternatives. Examples of environmental applications focused on economic expertise or skills should be developed and should become part of the core curriculum.

Computers

Computers have become so integrated into work processes that it's hard to believe that 10 years ago, most people didn't have direct access to them, and hardly anyone was using them as a routine calculation or modeling tool. Today, computers are used by engineers for electronic mail, to access off-site resources (The Net), modeling, routine/tedious computational analysis, statistical evaluations, cost estimating, process and treatment simulations, risk analysis, cost-benefit analysis, and many other tasks. They so thoroughly permeate industry today that to say that computer education should be integrated into course work seems too obvious and simplistic. But a word of caution may be appropriate. There is sometimes a belief that the computer is an end in itself instead of merely a tool to help do a job. Students need to appreciate that, while the computer can churn out elaborate data sets, it cannot interpret them, and it cannot make a reasoned decision based on those data. That, at least for the time being, is still the purview of humans. There is no doubt that computer skills are vital, but they contribute only when used in the context of a business need or a problem to be solved. All engineering courses should integrate the use of computer skills and tools to advance the students' productivity, but should also ensure that students understand that the decision-making stays with them.

Nontraditional, Nontechnical Skills

A recommendation to bolster the scientific and engineering foundations of undergraduate programs will undoubtedly have wide support among practitioners. After all, it merely expands what they already do. The other side of things may be less familiar, but it, too, is vital to preparing students to flourish in the workplace. Possessing nontraditional, nontechnical skills is primarily what separates the way things used to be from the way things are. The nontraditional, nontechnical skills are those that generally enable the engineer to operate effectively at the interface of technology and human beings: regulators, the public, the media, and co-workers. There are three main areas that need to be addressed: communication, cultural diversity, and out-of-the-box thinking.

Communication. Whereas in the past, the engineer may have operated quite comfortably and efficiently in relative isolation, in today's climate interacting with others is the way the job gets done and often it is the job. It is part of the job today to inform, transfer technical information, persuade, negotiate, brainstorm, etc.; in other words, to communicate—both externally and internally.

Externally, environmental engineers represent their companies in a variety of forums and for a variety of reasons. For example, they speak at public meetings, they testify before congressional committees, and they negotiate with regulators for permits. To many of these groups, the engineer is the company and how capably he or she presents technical information determines whether the company is understood and accepted. It doesn't make any difference if an engineer can calculate to ten decimal points that the expected concentration of a given substance at a certain point will not be harmful if he can't convince a regulator that his calculation is accurate. It doesn't make any difference if an engineer has designed a process that ensures no contaminants are released to the environment if she can't convince the public that the conclusion is based on honest data and a sound scientific approach. Communicating effectively is often made more difficult because different audiences may require different messages about the same project. For example, the engineer speaking to a community group to explain how a facility will remediate a chemical spill may need to use plain language that is free of acronyms and to avoid deep excursions into technically obscure explanations. The same engineer discussing the same spill with regulators may use technical terms and calculations that are understandable to both parties. Communicating a message in a way certain way for a certain group is not being inconsistent, nor is it being misleading. It is simply communicating a message so that a specific group can hear it.

Communication is not only vital in dealing with those outside the organization, it is also central to the way work is done inside. A logical outgrowth of a more holistic approach to environmental management is that most projects are implemented by teams. Each member of the team has a particular area of expertise to contribute and certain responsibilities within the project. If the process is to produce the desired horse instead of the much-maligned camel, each member of the team must understand the team objective, team processes, and his or her own role.

Good communication techniques should be a part of routine class work. For example, classroom approaches can employ class presentations and other approaches to encourage students to become more comfortable speaking in front of an audience. In addition, making a communication course (or two) a requirement may serve students well down the line. While it is unlikely that a separate course in teamwork would pass muster, methodologies should be employed within the existing curriculum that require students to work as teams so they become effective within that process; for example, the waste prevention team project previously recommended.

Cultural Diversity. Today's work force is no longer homogeneous; its diversification is a long-standing goal of industry. Further, the global nature of business today means that engineers are working in unfamiliar surroundings and cultures and yet they must maintain their efficiency. Preparing students for such multicultural exchanges may be difficult given an already crowded curriculum, but at a minimum an awareness that we now operate globally should be fed into the classroom. For example, courses on environmental regulations should be global in scope. More intensive efforts to broaden students' perspectives should also be evaluated. Students should be encouraged to study a foreign language, and many universities have special curricula, such as Women's Studies, which students might consider as electives. Going a step further, many institutions are developing or already have in place international study opportunities for science and engineering students. In 1993, however, only 2.3% of US undergraduates studying abroad were Engineering majors, even though Engineering majors accounted for 5.3% of the B.S. degrees granted that year (Brennan 1996). This must increase as industry expands its global operations. Students will undoubtedly participate in all of these areas to the degree they are comfortable, but engineering programs have an obligation to raise students' awareness of the multicultural workplace.

"Out-of-the-Box" Thinking. Meeting the environmental challenges facing the world today will require everyone's best effort. This is particularly true in the area of environmental remediation where problems often seem to resist traditional approaches, particularly from the standpoint of affordability. There are few "off-the-shelf" solutions that will work with every contaminant in every setting or that will be cost-effective in every application. The "right" solution is often cobbled together using a combination of approaches. This means that today's engineers must be "out-of-the-box" thinkers. That is, they must be able to apply familiar, fundamental principles and technologies to unfamiliar and often difficult-to-predict settings. Remediation applications can be difficult and the uncertain boundary conditions create significant engineering challenges. In short, engineers must be trained to be decision makers in the face of highly variable conditions. Clearly, this is not a candidate for an independent course. Rather, it is a mindset that should permeate all classwork. The unorthodox proposal or solution must be encouraged and respected by faculty and student peers and must be fairly evaluated on how well it can solve the problem, not how closely it conforms to classical engineering approaches.

Conclusion and Recommendations

The long and short of it is that the only way we can improve our education of environmental engineering students today is to expand the programs. From industry's perspective, we increasingly rely on technical personnel that embody not only all of the traditional skills and strengths but also the flexibility to branch out into new areas—both technical and non-technical. Colleges and universities can prepare students to function in this role by:

- Continuing and building upon already strong technical programs. In addition to core engineering courses, students should be encouraged (or mandated) to select electives in related basic scientific fields such as chemical engineering, chemistry, and biology.
- Adding courses, primarily as electives, that address areas with emerging environmental importance. Such courses would include risk

assessment; fate, effect, and transport; life-cycle analysis; cost-benefit analysis; and toxicology.

- Ensuring that students have a basic global understanding of environmental policy, legislation, and regulation.
- To the extent possible, integrating environmental issues, such as waste prevention, into existing courses.
- Ensuring students have basic computer skills and that they understand the appropriate and contextual role of computers in the workplace.
- Preparing students to become intellectually honest and ethical professionals.

In the nontechnical area, the curriculum and classroom methods should be expanded to:

- Require students to be proficient in a variety of communication modes or, at a minimum, ensure that they understand basic communication strategies and principles and are prepared to apply these skills in a public forum.
- Structure classroom procedures and approaches to promote an understanding of how to work as a team with individuals from other disciplines.
- Foster an awareness of and respect for the diverse and multicultural, multinational work force.
- Engender a global mindset and encourage students to study a foreign language or to take advantage of opportunities to study abroad.
- Create a classroom environment that supports and encourages "out-of-the-box" thinking.

Expanding the curriculum to accommodate all of these issues will seriously strain both the student's time and the institution's resources. It is doubtful that all of this can be accomplished within the confines of the current four-year program. If changes are to be made, that structure must expand, and there are several ways that might be accomplished.

- Institute a five-year program. Expanding into the fifth year clearly gives students more time to take both core engineering courses and to add the elective courses (both technical and nontechnical) necessary to contribute fully in today's workplace. This may pose hardships to some students, but these will be offset by long-term benefits to the profession and the students themselves. Students must understand that the time they spend in school is small compared to the time they will be in the workplace. Taking the extra time to become fully prepared will help ensure that their careers are fulfilling and rewarding.
- Partner with industry to expand cooperative programs, such as, summer, semester, or year-long internships in industry. Such opportunities could be structured so that students receive academic credit at the same time they are earning money and developing a more realistic vision of their intended career. Students may be more accepting of the increased academic load if they can see the connection of these ancillary areas to the practical world. Providing work-study opportunities may help make this connection. Working with practicing engineers would also help promote a sense of professionalism that would carry back into the classroom.
- Restructure the curriculum to include more required courses and fewer electives. This would help ensure that students receive a firm grounding in basic science and engineering.
- Restructure the program so that students begin work in their major field earlier in their academic career. This would allow students who are committed to pursuing a degree in environmental engineering to access courses earlier and increase the number they can take over four years.

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Role of Practitioners in the Capstone Design Course at Syracuse University

Raymond D. Letterman

Introduction

The Department of Civil and Environmental Engineering at Syracuse University has two undergraduate programs, a traditional civil engineering track and a newer environmental engineering program. Both programs are ABET accredited. The total undergraduate enrollment is about 180 students, divided almost evenly between the two programs. There are several Master of Science programs (with fifty full-time equivalent students) and a Ph.D. program with ten students.

The Department has ten full-time faculty, three in the geotechnical area, two in the structures area, and five in the environmental area. Seven practicing engineers from the Syracuse area engineering community serve as adjunct faculty and teach several upper-division required courses and a number of technical electives. This combination of research oriented, full-time faculty and experienced adjunct faculty is believed to be an effective way to prepare undergraduate students for professional careers in civil and environmental engineering.

Senior Capstone Design Course

The capstone design course is taken by most students in the second (spring) semester of their senior year. The course is four credit hours and it meets three times a week for three hours each session. (There has been faculty discussion about whether or not this schedule is consistent with only four credit hours, but no effort has yet been made to change the schedule or credit hours.) It is clear, however, that given present course objectives and substantial content, the nine hours per week that have been allocated are needed.

Students from both programs (civil and environmental) take the capstone design course at the same time. One year a design problem was used (the rehabilitation of a large pump station in a combined sewer system) that groups from both programs could work on cooperatively, but lately there have been two design problems, one that tends to emphasize the structures, geotechnical and transportation areas and one that has an environmental focus. Students choose the problem they want to work on. Every year several civil engineering students choose the environmental project but environmental engineering students rarely pick the civil engineering project, probably because most of them have not taken the structural engineering course sequence and the transportation course.

The students work in groups of five or six. Individuals are assigned to a group by the instructor based on their grade point average (GPA). The goal is to have each group include students with high and low GPA's and possibly, a range of attitudes and work habits. Each group has a project manager elected by the members.

Each student group is required to prepare mid-semester and final written reports with supporting documentation including concept drawings and other materials. The mid-semester reports are edited and graded by the instructor. A mid-semester oral presentation is required of each group. The presentations are videotaped by a university service and each group is required to use their video tape to prepare a written self-critique.

The design problems are contributed by local firms and agencies. (Typically the principals and contact people at these firms are Syracuse graduates and/or advisory board members and they have always been enthusiastic about helping.) Most of the projects to date have been designs that were just completed and where construction was commencing. Problems with a significant hydraulics component seem to be favored for the environmental engineering groups while three of the four civil engineering problems focused on bridge and highway design. The design problems (for the period 1992–96) and their major contributor are listed in Table 13-1.

Table 13-1
Projects of the Last Four Years for the Senior Capstone Design Course

Design Problem	Contributor
Rehabilitation of the Gorge Pumping Station, Niagara Falls, NY	O'Brien and Gere Engineers, Inc., Syracuse, NY
Onondaga Lake water quality improvements, Syracuse, NY	Various consultants and public agencies
Replacement of the bridge over Conrail tracks and highway relocation, East Syracuse, NY	New York State Department of Transportation, Syracuse Regional Office
Replacement of the Limestone Creek bridge, Rt. 5, Fayetteville, NY	New York State Department of Transportation, Syracuse Regional Office
Water distribution system improvements and storage tank design, Niagara Falls, NY	O'Brien and Gere Engineers, Inc., Syracuse, NY
Bridge and highway design, Mudmill Rd. over Rt. 81 Brewerton, NY	New York State Department of Transportation, Syracuse Regional Office
Expansion of a wastewater treatment plant, Town of Wappinger Falls, NY	

Using real upstate New York projects located within driving distance can be problematic. In one case construction began before the end of the semester and students drove to the project site and took pictures of the work in progress. This type of "research" has not been encouraged, but obviously the students won't be penalized either.

Engineers from the local agencies and consulting firms who prepared the design problems (and provided the support materials including maps and background information) have attended the presentations (mid-semester and final) and have acted as "clients" or "concerned public". After the presentations, they provided written comments that were given to the students.

At the end of the semester the students were required to complete a self-evaluation form and peer evaluation for each member of their group. The evaluation form asked questions about level and quality of effort by each person. The peer/self evaluation "scores" were used by the instructor to prepare the final grades.

Occasionally, the non-engineers are asked to speak to the student groups. For example, in the year the civil engineering students designed a replacement highway bridge over Limestone Creek in Fayetteville, NY, the mayor of Fayetteville spent several hours talking about socio-political and esthetic issues and the chair of the local historic review commission, an architect, discussed historic preservation issues that pertained to the area around the bridge.

In recent years short presentations (1 to 2 hours) have been made by representatives from firms that sell relevant equipment and supplies, e.g., pumps, water storage tanks, and treatment equipment and chemicals. They often bring promotional and technical material (videotapes, brochures and manuals) that they give to the students and which are made available in a library area that is part of the undergraduate design studio.

Professional Practice Seminar

Several years ago the Department decided to include professional practice issues in the civil and environmental engineering curricula. The "course in a box" materials were obtained from Ron Bucknam at the University of Washington and the Institute for Professional Practice in Silver Springs, MD. A first consideration was to use the materials in a new, senior-level course but it was decided, based on a number of constraints, including limited time and faculty resources, to try an "experiment" in which a professional practice seminar is included in the senior capstone design course. The topics included in this seminar are listed in Table 13-2.

Table 13-2
Professional Practice Seminar Schedule, Spring 1993

CALENDAR OF PROFESSIONAL PRACTICE CLASSES FOR CIE 475
SPRING 1993

Fridays	Topics	Lecturer
January 15	• Introduction • Professions and professionals	S.P. Clemence
January 22	• Types of organizations • Staff mix • Organization chart	O. MacMurray
January 29	• Defining markets • Market share • SOQs • Marketing projections/clients • Public sector RFQ/SOQ/RFP process • Private sector marketing • Bidding • QBS selection • Proposal preparation	O. MacMurray
February 5	• Types of contracts • General conditions	O. MacMurray
February 12	• Role of project manager • Project tasks, scope and budget responsibility/authority allocation • Utilization • Goals for profitability • Personnel management • Team communications	R. Simberg
February 19	• Motivation • Leadership • Monitoring project success • TQM • Value engineering • Permitting client follow-up	R. Simberg
February 26	• Ethics in professional practice — ethical theories and models — videotape and case histories	R. Simberg
March 5	•Ethics in professional practice — case histories	R. Simberg
March 12	**No Class—Spring Vacation**	
March 19	• Communications to avoid losses • Project overruns • Accounts receivables	B. Gidlow
March 26	• Contract language/clauses/pitfalls	D. Lerner
April 2	• Insurance—general and professional	B. Gidlow
April 9	**No Friday Class**	
April 16	• Limitation of liability • Other loss prevention techniques	TBA
April 23	• Dispute resolution methods • Being sued	TBA

The professional practice seminar is conducted during one of the 3, 3-hour sessions of the capstone design course. Typically the seminar is held on Monday or Wednesday afternoon. In the first year of the seminar it was held on Friday afternoon and that was a mistake. Attendance is required and each student must sign an attendance sheet. The attendance sheet is not popular but there is good evidence that without it some sessions would be poorly attended. Students are asked to purchase Bucknam's course lecture notes *Issues in Professional Engineering Practice* (Bucknam 1992) and a book on professional ethics in engineering (Martin and Schinzinger 1989). One year Culp and Smith's (1992) *Managing People (Including Yourself) for Project Success* was required instead of the Martin and Schinzinger book.

In the first year of the professional practice seminar seven outside speakers were invited, including the chief engineer of a local environmental engineering firm, the CEO of a local civil/environmental engineering firm, the retired Chief Engineer of the New York State Department of Transportation and the semi-retired owner of a large local contracting firm. Several lawyers from two local consulting firms helped with the material on contracts and legal issues.

Each of the outside speakers gives at least one 2.5 to 3-hour presentation. Some have given as many as four, two and a half-hour talks. To help them prepare, each speaker is provided with a copy of Bucknam's IPEP outline (Bucknam 1992) and a discussion is held about what should be emphasized. For the last couple of years the focus has been more on ethics, spending 3 or 4 (out of 12 to 15) sessions on this alone. This has been done (at the expense of other professional practice issues) because the students seem to appreciate this material more than some of the other topics and most faculty believe it is important. One of the speakers commented that some of the professional practice material that had been covered was not that relevant for the person who is 0 to 5 years beyond graduation and that this might explain some of the problem with lukewarm interest.

Most of the ethics material is covered by the retired chief engineer of the New York State Department of Transportation, Dick Simberg. Two years ago, Simberg was provided with a temporary office in the Department during the spring semester and he posted office hours. He used this time to work with each of the student groups as they prepared their "skits" on ethical issues. He has also helped the students prepare for their project presentations.

Course Evaluation Results

One year the course evaluation form was used to ask the students if the professional practice seminar increased their understanding of professional practice issues. Eighty three percent of the thirty students who responded answered in the affirmative, ten percent said no and seven percent said they were not sure.

In the future, if a way can be found to conduct a survey, our graduates, people who have been working for two or three years, will be asked if it has been worthwhile to them to have covered professional practice material in the senior capstone design course.

A final exam is administered, (with mostly true-false, multiple-choice type questions) on the material in Bucknam's IPEP outline, supplemented with items from the lectures by the invited speakers. Two of the fifty questions are given below:

> *True or False.* Prior to about 1978, the codes of ethics of most national engineering societies prohibited competitive bidding for new projects. While not stated in the codes and canons, it is still the opinion of most professional engineers that selecting an engineering firm to design a project on the basis of competitive pricing alone is improper.
>
> *Communication with the team*
>
> Peter Drucker, the management consultant, said that 60 percent of all management problems are the result of poor:
>
> a. hygiene
>
> b. education
>
> c. communication
>
> d. none of the above

Some Thoughts About the Capstone Design Course and the Professional Practice Seminar

In each of the three years that practitioners were involved in the capstone design course plus professional practice seminar, an analysis was made of what seemed to work best and what to avoid or change the next time.

The best seminar sessions have been those in which active participation by the students was encouraged or required by the lecturer/instructor. The types of participation used include:

1) Student groups do skits in which they act-out situations that illustrate ethical problems. Many try to be clever and entertaining and this increases audience attention and participation.

2) Group discussion of ethical issues, usually after a group has presented their skit. The most spirited exchanges have involved ethical issues that the students relate to or fantasize about, e.g., accepting travel support for a visit to a prospective employer but during the trip adding a visit to a second interviewer.

One speaker asked each student to prepare a large name card that he could read from the front of the room and to place the card on the table in front of their seat. To encourage discussion, he called on each student by name. This significantly improved the amount and quality of interaction.

Requiring attendance at the professional practice seminar was painful for both instructor and students but it was probably necessary. Some students resent the requirement but the demands and distractions of the senior year tend to pull many students away from voluntary assignments, especially assignments where non-faculty, i.e., the invited lecturers, are effectively in charge.

Unfortunately, at Syracuse the capstone design course is the first time many students are asked to organize, as a member of a small group, their own attack on a complex, comprehensive engineering problem. A significant number have a difficult time organizing themselves and then mustering the required self-discipline. Some suffer what has been called "capstone design anxiety" and fall victim to self-defeating procrastination.

It has been tried (with mixed results) to help the students prepare for working together in groups. In two of the years this new format was used for the capstone design course, the semester started with 2, 3-hour sessions on group interaction and on understanding and respecting personality differences. The students took the Myers-Briggs Type Indicator (a test that determines an individual's personality type) and they did a role playing exercise, working in groups to build an object with tinker toys. The exercises were supervised and the test results were interpreted in class by trained staff from the Syracuse University Office of Leadership and Student Organizations. Most of the women in the class (about 1/3 of the students) thought these sessions were of significant value. Others, including a couple of senior faculty, were not as impressed and this feature was not repeated in the third year.

The faculty have begun to discuss ways in which students could be better prepared for the capstone design course (and, for that matter, graduation). Ways are being considered to integrate capstone design type activity, including work on small-scale, open-ended problems by groups of students (with input from and participation by local engineering professionals), in the curriculum before the senior year. At the present time most of the courses taught by department faculty (full-time and adjunct) are of the traditional "chalk and talk" variety. It is clear to some that greater cooperation and collaboration between faculty (both within the department and with other departments in the college and the university) will be necessary if the students are to be prepared for the changing landscape of professional engineering practice.

The faculty in the Department have not been unanimously supportive of the professional practice seminar as part of the capstone design course. One or two have been outspoken, saying that this time (3 hours per week) would be better spent lecturing on topics such as engineering economics or technical material that would improve the quality of the work the students do on the design projects or on the presentations.

Non-faculty speakers/lecturers have made suggestions for improving the IPEP course notes.

1) One has suggested that it would help if the ethics problems included material on alternative resolutions of the ethical problems covered by the examples. This lecturer has been using the proceedings of the NSPE (National Society of

Professional Engineers) ethics review board (where the alternative resolutions are presented) to supplement the material he uses from the "course in a box", i.e., the ethics problems in the Bucknam IPEP outline and the Gilbane Gold videotape.

2) One speaker has suggested that the material in the Bucknam notes does not focus enough on the problems and situations experienced by the entry level engineer. More material for entry level engineers might increase the interest and enthusiasm of the students.

The Department continues to debate whether or not the professional practice material should be covered within the capstone design course or if it should be the basis for a new, 3-credit hour course that is open to both undergraduates and M.S. students.

The capstone design course as presently configured is a very time-consuming responsibility for the full-time faculty member in charge. There are many tasks that must be completed in the fall semester, such as finding and working with the local practitioners who prepare the design problems and contacting and making arrangements with the speakers for the professional practice seminar. An attempt was made to lighten the load to some extent by organizing a group of faculty to assist with the capstone design course. Several members of this team were responsible for technical support with parts of the design problem and some helped with student presentations.

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The Practicing Environmental Engineer/Academia Interface: Optimizing Relationships

Arthur H. Purcell and Massoud Pirbazari

Abstract

Two significant forces are bringing environmental engineering practitioners and academia into closer working contact: Increasing complexities of environmental engineering challenges and decreasing academic budgets. Utilization of practitioners as adjunct, part-time faculty is consequently a growing feature of many environmental engineering programs. At present, however, it is an essentially a two-tiered system, with the adjuncts on the bottom tier. The consequence is sub-optimal practitioner/academia relationships, wherein practitioner resources are insufficiently utilized, and the practitioners, in turn, have limited motivations for contributing more resources. The problem is characterized by the very word *adjunct* that generally describes a part-time academic post for the practitioner: By definition, the term adjunct refers to "something added to another thing but not essentially a part of it." This poses a particular problem in environmental engineering, where complexities of field, compounded by continuous evolution of concepts and issues, require a careful integration of all teaching and research resources. Responsive mechanisms for linking the academic and practicing environmental engineering communities must be developed if the full benefits that each can offer the other are to be realized. Optimizing the practitioner-academia relationship, and developing guidelines for practitioner-academia partnerships, entail both administrative and academic issues, including:

- Modes of practitioner-academia communication and interaction
- Role of practitioner in environmental engineering program decision making
- Role of the practitioner in course development
- Role of the practitioner in research development
- Administrative and academic support for practitioners
- The practitioner and resource development
- A practitioner tenure system

The Practitioner in Today's Academic Environment

Several years ago one of the authors (AHP), then a part-time faculty member at an Eastern university, published a research paper which promoted a telephone call from an aerospace contractor offering research money. The contractor was in need of R&D support in the very specialized field covered by the paper. Would the researcher and his institution be interested in a contract, he asked. "Most certainly!" was a the reply, but first it will be necessary to run this through the department. This was quickly done. The result? Absolutely nothing. The environmental engineering department in question expressed no desire to develop a research project with a part-time faculty member. That kind of support, the department made clear, was not wanted.

Examining this incredible story from the perspective of the budget-conscious 1990s, one is tempted to regard it as a fluke of ancient academic history. Most assuredly, it would be argued, this kind of thing would not happen today. Yet evidence suggests that, in fact, it could well happen today — that the gulf between full-time, tenure-track professors, and part-time practitioner faculty continues to be wide at most colleges and universities; and that the result is generally very suboptimal relationships between these two groups that can easily replicate this kind of dilemma.

Today's college and university budget realities, combined with growing curricula complexities, would seem to dictate that environmental engineering — and all other — academic programs strictly optimize use of faculty resources. It follows that no program would choose to enlist teaching and research personnel that are not fully integrated into its activities. Nevertheless, that is what many programs are essentially doing, as they develop and utilize, on piecemeal and often arbitrary bases, their part-time, *adjunct* faculty bank. By definition, the term adjunct refers to "something added to another thing but not essentially a part of it." And, in all too many cases, this characterizes academia's attitude toward part-time practitioner faculty. Adjunct professors are hired at minimal cost to meet short-term needs, with relatively little thought given to their overall, longer term relationship to the institution, and the mutual benefits that could be derived from such a relationship.

For the part-time faculty member, the double dilemma of neither feeling, nor being perceived as, an essential faculty component significantly limits his or her academic effectiveness and motivation. A two-tiered situation thus exists. The second-tier images of the part-timer are familiar: Inadequate or nonexistent dedicated office space; low visibility; limited credibility with, and accessibility to students; lack of communication with full-time faculty and staff; low pay; lack of benefits; lack of job security; and few prospects for advancement. Despite these negatives, practitioner participation as part-time, non-tenure track faculty members in colleges and universities across the nation is widespread. "Adjunct professorships," notes one practitioner, "allow a university to make the most of scientists' skills and knowledge, while giving researchers from a range of workplaces access to the academic."

As we head into a new century of higher education, however, the adjunct, part-time faculty system must be carefully scrutinized to determine how it can better serve both practitioners and academia in the longer term. This is particularly important for environmental engineering, where developments outside of academia are constantly reshaping the field, and where practitioner input is thus essential to development of fully adequate teaching and research curricula. (Note: *adjunct* and *part-time* faculty can be defined differently by different institutions. In its 1993 report on "The Status of Non-Tenure-Track Faculty," the American Association of University Professors defines several categories of non-tenure track faculty. The discussion in this paper focuses on *part-time, non-tenure track practitioner* faculty members. The term *adjunct* is often used to describe this type of faculty member, even though some institutions utilize the *adjunct* title more specifically.)

Meeting Needs

The practitioner part-time faculty arrangement conveniently meets some needs on both the academic and practitioner sides. For academia these needs include the following:

- Real-world, up-to-date faculty field experience
- Special skills not available in full-time faculty bank
- Network of potential employers for graduates and clients for professors
- Network of potential funders
- Faculty requiring less than full-time support levels
- Faculty with minimal infrastructural needs

Real-world Experience. Perspectives of practicing professionals add critical dimensions to the classroom. Environmental engineering entails a very significant time-dependent component. The field is constantly changing, and use of practitioners is an indispensable means to keep academic programs updated.

A full-time professor who is five or ten years away from actual environmental practice is five or ten years behind many events in the field. "An industrial scientist," says Lewis (1993), "can give students a taste of the real world that isn't quite the same as traditional course fare. In return, he or she networks with basic researchers in a manner that can lead to fruitful collaborations."

Special Skills. From pollution prevention to design-for-the-environment, practitioners bring to environmental engineering programs special interdisciplinary training and skills not readily found within faculty ranks. Materials-trained environmental engineering practitioners provide illustrative examples. A recycling specialist can transfer leading-edge knowledge to teaching and research in this field, including qualitative and quantitative insight on how the theory and practice of secondary materials recycling differs. A process or product design-focused materials/environmental engineer can impart to students the intricate, and often trial-and-error process of lifecycle-based "materials greening" and "dematerialization" for lower environmental impact processes, products, and services. And both types of practitioners, can provide pivotal skills for development of pollution prevention-based research. An electrical engineering-trained practitioner, similarly, can bring considerable insight into environmental engineering applications of high tech — from advanced remote sensing and real-time emissions monitoring to development of ultra-low tolerance machining hardware and software to optimizing environmental information systems. A third important example lies in environmental compliance. A technically trained practicing environmental attorney can bring to the classroom perspectives on state-of-the-art knowledge of environmental regulatory and compliance trends and practices that are invaluable for the design of environmental engineering technologies.

The international arena presents a special area of need for practitioner faculty. As our economy globalizes, so do the environmental engineering practices that are an important part of the economy. Internationally experienced environmental engineering practitioners bring special skills which are found, at best, only in limited quantities on campuses. The difference between a professor who may spend a week, or possibly a semester, working abroad and a practitioner who devotes a large fraction of his or her time to international environmental engineering is vast.

Network of Potential Employers and Clients. The practitioner provides a direct interface with potential employers for graduates, as well as potential consulting clients for faculty. Through use of practitioner faculty, academia can short-circuit the process of developing professional relationships with outside companies and agencies.

Network of Potential Funders. A practitioner is a *de facto* emissary from his or her organization to the university, and serves as a direct link to potential sources of support from that organization.

Faculty requiring less than full-time support levels. For colleges and universities, part-time practitioner faculty represent very cost-effective sources of talent. They generally receive very modest stipends and no fringe benefits from academia, deriving their major sources of remuneration from outside.

Faculty with minimal infrastructural needs. Just as practitioners earn their livings outside of college and university budgets, so, too, do they meet their infrastructural needs. Their off-campus offices, laboratories, and other facilities are paid for by non-university funds.

Practitioner Faculty Member Needs Met by Academia. Practitioners seek part-time faculty affiliation for a variety of mostly nonremunerative reasons that may include:

- Intellectual fulfillment
- Teaching/research opportunities
- Increasing practitioner institution visibility
- Prestige of affiliation with institution of higher learning
- Potential research partners
- Potential source of new employees
- Salary supplement

Intellectual fulfillment. Intellectual fulfillment is perhaps the main motivation for practitioners to affiliate with college and university faculties. In the words of one practitioner, "Being an adjunct allows versatility, expanding your horizons" (Lewis 1993).

Teaching/research opportunity. Many practitioners seek to make the teaching experience an integral part of their professionals lives, for both practical and intangible reasons. Teaching provides fulfillment, but also is a useful tool for honing communications skills. And teaching, by its very nature, offers a sense of satisfaction through instilling useful knowledge in other human beings. Practitioners may seek campus research affiliations for similar reasons, combining their interests in working with students with the need to secure special expertise and/or research facilities.

Increasing Institution Visibility. Many organizations actively encourage their employees to become associated with colleges and universities to increases organization visibility.

Prestige of Affiliation. For some, a college or university affiliation adds prestige to their work, potentially enhancing career opportunities.

Potential Research Partners. Finding suitable partners and/or facilities for research of interest to practitioner institutions is made considerably easier through academic affiliation. Practitioners can network on campus with a large potential research roster.

Potential Source of New Employees. Just as a campus presence enhances linking up with research partners, it also facilitates the process of meeting — and evaluating, through classroom teaching — potential future employees of the practitioner institution.

Salary Supplement. Part-time teaching provides extra remuneration to practitioners; the generally minimal pay levels, however, "pitiful" according to Robert (1990), tend to make this a lower priority practitioner reason for teaching.

Complementary Needs Requiring New or Improved Mechanisms for Meeting Those Needs. On the surface, at least, it would appear that the system of utilizing practitioners for part-time faculty is, in the parlance of the 1990's, a "win-win" situation; practitioners are able to expand their professional horizons, while colleges and universities add cost-effective dimensions to their faculties. Nonetheless, both practitioners and academia sense significant problems with the system that must be mitigated if it is to meet future needs of participating parties. According to Marilyn Robert (1990), an experienced practitioner/part time faculty member, serving as a part-time faculty member, represents an "ephemeral academic liaison" that "is a tenacious position at best." She argues that the system virtually precludes part-time faculty members from attaining full-time status, and thus limits both usefulness and credibility of practitioner faculty. "As corny as it may sound," says Robert (1990), "behind this title [of part-time, adjunct faculty member] stands a shining set of ideals: a belief in the excellence of education; a dedication to our profession. Such adjuncts are not only proud to have earned their degree but are also, for the most part, innovative, conscientious, teachers. However, neither students nor most of the university faculty members appear to recognize an adjunct as an expert teacher/colleague."

The American Association of University Professors, by the same token, sees the practitioner faculty member as a threat to long-term academic freedom and viability. In its report on "The Status of Non-Tenure-Track Faculty," AAUP (1993) charges that "the large number of faculty who now work without tenure leaves academic freedom more vulnerable to manipulation and suppression. The professional status of faculty suffers when so many are subject to economic exploitation and demeaning working conditions inconsistent with professional standards."

For several reasons, the practitioner-academia relationship is generally a suboptimal one. While in a few instances a good fit may be achieved — e.g., a university is able to claim a renowned industry researcher on its roster, while the researcher, in turn, has direct access to the school's facilities and graduate talent — the "ephemeral" label that Robert (1990) ascribes to adjunct teaching is probably much closer to the rule. Developing a productive *sense of belonging* — one with which both part-time and full-time faculty members are equally comfortable — is a core challenge to optimizing the practitioner/faculty member/full-time faculty relationship. What constitutes that sense of belonging? Examining five core issues directly related to practitioner-academia relationships brings insight into this and related problems, and suggests mechanisms for addressing these problems. These issues are:

1. Quality of Courses, Curricula, and Teaching
2. Quality of Research
3. Collegiality of Faculty
4. Quality of Relationship with Students
5. Long-Term Faculty Stability

Issue 1: Quality of Courses, Curricula, and Teaching

Practitioner faculty members (PFMs) and full-time faculty (FTF) share strongly converging objectives in terms of course, curricula, and teaching quality. They both want the best quality available for their particular programs. Yet there is much difference of opinion as to how and whether the two groups should interact to achieve this objective. PFMs may be allowed — or sometimes encouraged — to introduce new courses oriented toward their particular professional specialties, and yet they are seldom included as part of the curriculum decision-making process. But while practitioner faculty members may be concerned about being left out, full-time faculty worry about PFM quality — about the course content and teaching quality offered by part-time peers with whom they have limited contact and over whom they have essentially no control. Equally, they worry about the ability — and appropriateness — of an outsider to contribute meaningfully to curriculum development.

By job definition, PFMs should have much to contribute to the teaching and curriculum development process. If they are considered worthy of teaching at an institution, then they need to be included in some of the decision-making processes surrounding the teaching. One mechanism for accomplishing this would be instituting a formalized practitioner curriculum input process in which PFMs periodically submit to a special full-time faculty committee their perspectives and suggestions on curriculum development; this committee would, in turn, develop formal recommendations based on this input. Including PFM representatives in faculty decision-making meetings would also be appropriate.

Quality of practitioner teaching is a particular area of concern for full-time faculty. Both sides have important roles to play in alleviating this concern. Since the quality of teaching is not independent of the logistical support received by the teacher, PFMs should receive the same level of support — e.g., teaching assistants, classroom size limitations, etc. — as do their full-time counterparts. Concerns over practitioner teaching quality can be allayed through faculty development seminars, presented by full-time faculty for part-timers to ensure uniformity of teaching parameters. Cooperation between PFMs and FTFs in developing and presenting courses, similarly, should be encouraged.

Issue 2: Quality of Research

The outside world often criticizes academia for failing to bring relevance to its research agenda. Former U.S. Senator William Proxmire's "Golden Fleece" awards were a visible case in point. The Wisconsin lawmaker would periodically present one of his "awards," with scathing commentary, through the national media. Proxmire was sometimes way off the mark; he was, in fact, successfully sued by one academic who, having used primates in his government-funded research, was publicly mocked by the senator for "making a monkey out of the taxpayer." Yet the Golden Fleece campaign, and related efforts scrutinizing publicly funded research, have raised legitimate questions about the relationship of academic research to the national agenda, and have prompted more careful scrutiny of research priorities.

The practitioner faculty member can provide indispensable reality checks in this regard, helping environmental engineering (and other) programs orient research toward viable, long-term issues of concern in the environmental management community. And, quite importantly, the PFM can be a source of research funding.

A number of industry-university programs have been initiated to mesh research resources of these two sectors. Resulting programs have brought mixed results for practitioners. On one level, they have helped them achieve reasonable credibility with full-time faculty, since they offer both scientific and monetary resources to academia. At the same time, though, university-industry research programs rarely offer any meaningful type of faculty status to research practitioners. And for the many practitioners whose organizations lack significant research capabilities, their opportunities for participating in university research are quite limited. As with above-noted issues related to curricula and teaching, universities can engage in a number of activities to take advantage of the value of PFMs in their research agendas; these range from joint project development and execution to utilizing practitioners as major project advisers.

Issue 3: Collegiality of Faculty

Collegiality is a literal basis for development of the academic (sic) college system. For institutions of higher learning to succeed in their missions, a faculty that is able to work smoothly in tandem is essential. To date PFMs have been pretty much kept out of what could be called the *collegiality loop.* To function with maximum effectiveness, however, the PFM must have a strong sense of belonging to the faculty of which he or she is supposed to be a part. There are both tangible and intangible methods of sharing which can accomplish this objective.

Shared Decision Making: Per the previous two sections, PFMs should, to some substantive degree, be part of research and teaching decision-making. While few academic programs would be prepared to embrace PFMs as full-time members of decision-making bodies, much can be done to make them bonafide academic stakeholders. The suggested formalized input process for curriculum development is one example of how to do this.

Shared Knowledge: There is probably no better way for faculty to get better acquainted with, and to gain mutual respect for each other than through scholarly seminars. Regular inclusion of PFMs in seminars as speakers and discussion leaders thus represents an important collegiality building mechanism; encouraging joint PFM-FTF professional meeting presentations and publications is another. On a more fundamental level, part-time faculty should be carefully surveyed to document their capabilities and accomplishments. This knowledge should be shared with the full-time faculty through departmental newsletters, electronic data bases, and/or special publications distributed to both faculty and students.

Shared Facilities: A major source of practitioner faculty anxiety lies in the lack of office space and related facilities. Generally PFMs have no office space, or perhaps one or two small rooms are shared by all PFMs. The main argument for limiting such PFM space is that practitioners do not spend that much time on campus. The inverse, however, also applies: PFMs have little incentive to spend more time at their academic locations if there is literally no place for them to sit down. The practitioner faculty invisibility of which Robert (1990) has written is greatly reinforced by the lack of dedicated office space for PFMs. Office and facility space, just like other dimensions of teaching and research, should be available to practitioners as if they are regular faculty.

Shared Social and Ceremonial Activities: How many universities invite their PFMs to don their colors and joint graduation ceremonies? Very few, despite the fact that many graduates studied under practitioners. And how many departments formally introduce their PFMs to regular faculty? Again, very few; it is not uncommon for a practitioner to be acquainted with only one or two members of the department in which he or she regularly teaches. From the formality of commencement exercises to faculty receptions, there are many opportunities to promote PFM-FTF collegiality through social intermixing.

Issue 4: Quality of Relationship with Students

"One of the most distinctive facets of the university from the early centuries of its development," says Nannerl Keohane (1993), "has been the juxtaposition of advanced professional training with baccalaureate education. The double layer of training has become the definitive characteristic of the university in America, and to a large degree throughout the world." Practitioner faculty form a vital part of this double layer, yet their credibility, as well as substantive interactions with their students, is often very limited. It is up to the university to ensure that students recognize the full legitimacy of part-time faculty members, and to facilitate PFM-student contact. At the same time, practitioners must make greater efforts to be available to students. Per above, administrative upgrades such as providing dedicated office space and telephones lines for practitioner faculty would significantly enhance this process.

Issue 5: Long-Term Faculty Stability

Part- and full-time faculty share very complementary needs when it comes to issues of faculty stability. PFMs would like job security. The faculty seeks continuity. At the present time, however, several factors dictate that *instability* and *discontinuity* may be the prevailing watchwords in PFM-FTF relationship. PFMs tend to be poorly compensated, do not receive fringe benefits, and have little or no assurance that good performance one semester will lead to a contract for the next one. Lack of such assurance translates into lack of motivation to make significant commitments to the host institution, which in turn translates into lost opportunities for both institution and practitioner. This situation can be readily ameliorated through: (a) upgrading PFM pay; (b) providing fringe benefits to PFMs; (c) institution job security-oriented hiring and performance review practices; and, (d) offering a tenure-track system for PFMs. At the present time, *serving as a practitioner faculty member* in an academic department and *increasing involvement in that department* are usually antithetical exercises; probably because of the second-tier esteem in which they tend to be held, PFMs are generally not considered worthy of attaining full-time faculty status. This is a clearly unstable, and unsuitable, state of affairs in need of change. Tenure-track systems for PFMs should be developed at two levels (1) For those seeking long-term part-time commitments from host institutions; and (2) For those interested in increasing their time commitments to full-time levels.

Anticipating Trends: Role of the Practitioner

Environmental engineering is a highly dynamic field of study. It is heavily time- and event-dependent. From ongoing development of new pollution abatement and prevention technologies to changes in regulations, outside forces are continually shaping the field and creating and refining sub-fields. Practitioners whose daily activities expose them to this process of change are thus of particular value to environmental engineering programs.

Leading and emerging environmental concepts that entail critical environmental engineering dimensions will include:

- Advanced Pollution Prevention
- Energy-Environment Synergies
- Engineering for Sustainability
- Environmental Justice
- Extended Lifecycle Design for the Environment
- Indoor Environmental Management
- Industrial Ecology and the Ecologization of Environmental Engineering
- Materials Optimization, Dematerialization, and Next-Generation Green Materials
- Next-Generation Risk Management
- Product Stewardship
- Public-Private Partnership Approaches to Environmental Regulation
- Reaching Zero-Emission
- Total Quality Management as a Tool in Environmental Engineering

"Engineering," note Pohland and Anderson (1996), "will be challenged as never before to shape the nature and quality of life in the 21st century. Engineering education, and more specifically environmental engineering education, must be at the forefront of the effort to meet this challenge." This challenge is clearly spelled out by the complexity of the above and related concepts that environmental engineering education will likely be incorporating into curricula in the coming years. The potential role of practitioner faculty in helping meet the challenge, through adding knowledge and perspectives that can only be found outside of academia, is thus significant.

Guidelines for a New Generation of Fruitful Practitioner-Full-time Faculty Relationships

It will be in the best interests of both the environmental engineering education community and part-time faculty practitioners to develop a set of uniform guidelines on the role, rights, responsibilities, and remuneration of practitioner faculty members that reflects next-generation education needs. The following recommended practices should be included in the guidelines:

(1) Quality of Courses, Curricula, and Teaching

- Institute mechanisms for formal practitioner participation in course and curriculum development that integrally include emerging environmental engineering issues in which practitioners hold special knowledge and skills
- Assign Teaching Assistants/Graders for PFMs on the same basis as for FTF
- Host faculty development seminars for practitioners

(2) Quality of Research

- Institute mechanisms for formal practitioner participation in research development and execution that integrally reflects emerging environmental engineering challenges in which practitioners hold special knowledge and skills
- Encourage joint PFM-FTF development and execution of research projects and resulting publications

(3) Collegiality of Faculty

- Survey capabilities of practitioner faculty and communicate these capabilities to full-time faculty and students
- Conduct periodic faculty-student convocations or receptions to introduce PFMs
- Include practitioners, on a regular basis, as speakers and discussion leaders in departmental scholarly seminars
- Include practitioners in ceremonial and socially oriented events, such as graduation ceremonies

- Maintain a standing committee to monitor practitioner-institution relations and make periodic recommendations for enhancing them

(4) Quality of Relationship with Students

- Provide students with background information on PFMs
- Host special PFM-led student seminars
- Provide dedicated office/desk space, telephone, and clerical services
- Require on-time campus commitments from PFMs

(5) Long-Term Faculty Stability

- Increase PFM pay to level commensurate with their efforts
- Provide PFMs with fringe benefits commensurate with their compensation
- Institute incentive and tenure-track programs for practitioner faculty that would: (a) provide a standardized basis for host institution to gage practitioner faculty member performance and contributions; and (b) provide incentives for PFMs to increase their commitments to host institutions.

Some of these recommendations were incorporated into an AAUP report on part-time faculty that was published sixteen years ago, as well as its 1993 update. The 1980 report recommended that: (1) a tenure system should be available for some part-time faculty; (2) Job security procedures for part-timers be upgraded; (3) part-time faculty should participate in governance; and (4) part-time faculty should receive fringe benefits. The 1993 AAUP report on non-tenure track faculty amplifies these recommendations, offering eight additional recommendations that range from mechanisms for evaluating performance of part-time faculty to policies for assigning office space and support services. The tenure issue for PFMs is not new. Seven years before the 1980 AAUP report, a Commission on Higher Education study, sponsored by AAUP and the Association of American Colleges, also called for a tenure system for part-time faculty (AAUP 1993).

Guidelines and recommendations are, of course, only as good as the word of their adopters. Lesko (1995), the director National Adjunct Faculty Guild, based in Ann Arbor, Michigan, has called for academic associations to take on the role of enforcing guidelines to stop what he calls the "exploitation" of part-time faculty. "Unfortunately," says Lesko, "not one (of a representative group of university policy statements on utilization of part-time faculty) calls for sanctions against institutions or individuals who do not comply with those guidelines, or who otherwise treat part-time and temporary faculty members shabbily." The challenge, then, is to develop a set of part-time faculty policies that will significantly benefit all parties, and thus provide incentives from within and without for enforcement.

Practitioner Faculty and Next-Generation Environmental Engineering

When properly integrated into the academic system, practitioner faculty can bring to their host institutions critical dimensions only found outside of academia. From new sources of knowledge to new sources of funding, practitioners represent vital add-ons to the next generation of higher education. Stanford University president Donald Kennedy (1993) has stated:

> "...Never before have our universities lived in a more abruptly changing society. To speak of 'academic rigor' by way of appealing to the disciplinary status quo is self-evidently anachrostonic now. We need to open up the rigid cages of institutional thought and custom to new cultures, new alignments, and new problems..."

Strengthening of the part-time/full-time faculty relationship to optimize the benefits that part-time faculty can bring to universities can go a long way to opening up these cages, and usher in a new generation of mutually beneficial cooperation between academic and practitioner sectors.

The field of engineering is particularly ripe for an examination and upgrading of the PFM-FTF relationship. From the available literature it appears that the bulk of activity geared toward developing this relationship has been in non-engineering areas. Environmental engineering specialists Frederick Pohland and William Anderson (1996) predict that:

> "...future environmental engineering education can be envisioned as a partnership between academe, practice, and the student that, of necessity, must be highly adaptable to the demands of the future, while producing graduates

> that are competitive and capable of efficiently working together in teams to identify and solve complex problems in all societal sectors, including academe itself..."

Kennedy (1993), similarly, has called for a "new coalition" to meet the needs of the university of the future. Practitioner faculty, with unique knowledge, resources, and skills, need to be an essential part of that coalition. They will be if the environment for their participation is made equitably hospitable.

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The Role of Consulting Engineers in Engineering Education

David E. Thompson

Abstract

The application of the knowledge gained by students to the solution of problems in the real world is significantly affected and influenced by factors that are not covered in traditional engineering education curricula. Professional ethics, business development, contract formation, business economics, legal obligations, risk management, insurance requirements, dispute resolution procedures, project management, personnel management, and quality management are just a few of the factors which can significantly influence the way engineering services are delivered.

Consulting engineers in practice are most familiar with these factors and the ways in which they influence engineering service delivery. In order to provide students with a well-rounded engineering education and for them to understand the framework within which their talents must be applied to the solution of engineering problems, it is meaningful and important to facilitate programs which discuss the implications of these non-technical factors on the delivery of engineering services at the graduate and undergraduate level.

The Institute for Professional Practice (IPP) is a non-profit educational organization, founded by practitioners, to provide educational services focused on the non-technical issues affecting the delivery of engineering services. The Institute's "Issues in Professional Practice" course is used in over 150 engineering programs in the United States.

This paper will describe the program as it is structured in one university engineering program in a way that capitalizes on the resources of IPP and local practicing engineers.

Background

The practice of engineering in the United States today is significantly more complex than it was a decade or two ago and the complexities are increasing at an accelerated pace. Not only are the design methods becoming more complex and robust, but the external environment, within which our solutions must by applied, is much more demanding. In fact, for many projects today, the principal engineering challenges are not the technical ones, but the non-technical issues. Most importantly, the ability of an engineering firm, to understand and manage the non-technical issues is the differentiation that will be most influential in determining the firm's future success and its ability to continue to deliver good engineering into the future.

For example, the engineering profession today is confronting unprecedented pressures for competitive fee bidding as a method of designer selection as compared to a process involving Qualifications Based Selection (QBS). In the former process, technical services (scope and competence) are considered equal for all firms, and price in the selection criteria. In the later process, qualifications and experience with similar projects is the basis for selection of a firm followed by mutual scope development and fee negotiations.

The process of fee bidding is fundamentally flawed and, if allowed to proliferate, will significantly degrade the quality of engineering services delivered in the United States. When a firm is selected based on minimum fee, the focus is on quick adequate solutions. Why spend time on a sophisticated analysis which might reduce the quantity of steel or concrete in a structure when a simple analysis will produce an adequate solution, even though more costly?

In this example, the Owner might save a few thousand dollars in design fees, but pay tens of thousands in additional construction costs (and not know it). However, worst of all, the designer is not permitted or motivated (assuming he wishes to survive as a business) to use newer, better, more complex analyses and design tools. In addition, the designer's staff are restricted from exploring innovative solutions which may deviate from faster "cook-book" methods and may even be prohibited from using more current design methods which require time, if quicker, more conservative methods exist.

The current movement toward fee bidding is fueled by naive and uneducated Owners and, unfortunately in some cases, by uneducated engineers. Engineering can usually be done cheaper by short-cut analyses, minimal scope, and other tactics. However, cheap engineering is generally not what the Owner wants, and worst of all, it deprives the professionals from applying the education and innovation which is so important to the advancement of our profession. Many engineers either don't recognize the issues, or are unwilling to attempt to educate Owners regarding the consequences of fee bidding as a selection process for engineering services.

If the current movement toward fee bidding is to be reversed, it must be done by educating engineers and Owners. This process should begin in the classroom so that every engineering graduate understands how professional services should be procured and can, in-turn, educate Owners 'and others' clients. Time is being wasted teaching young engineers to use powerful and sophisticated analytical tools unless we ensure a delivery system that will permit their use in the real world.

A similar discussion could be presented for our legal system and insurance programs in the United States and their impact on the delivery of engineering services. Unlike methods of procurement, these systems are well developed and not subject to significant influence. However, a fundamental understanding of the legal yardstick used to measure the adequacy of professional engineering services can go a long way toward keeping practitioners out of court and managing the risk of incurring significant exposure to claims which may threaten the very existence of a firm and, therefore, its ability to continue to deliver services.

Since engineering services must be delivered within a well established legal framework and the obligations of engineers within this framework are generally well documented, the process of engineering education should include some exposure to the important issues and the legal obligations of a professional engineer to the public.

Similarly, issues related to professional ethical dilemmas, obligations of an expert witness, alternative dispute resolution methods, project management techniques, engineering business economics, technical writing skills , oral presentation skills, and many others are significant influences in the delivery of engineering services.

Young engineers entering the market place today as practitioners are ill-prepared to deliver services unless they have a fundamental awareness of these issues and their impact on their work.

The Institute for Professional Practice

The Institute for Professional Practice (IPP) was established in the late 1980's as a non profit educational organization with an initial grant provided by ASFE/ Professional Firms Practicing in the Geosciences. Subsequent funding has been provided by various professional organizations, insurance companies, universities and private individuals.

The mission of IPP is to:

> "Create an awareness of non-technical issues encountered in professional practice...which make a definitive difference between success and failure in an engineered project."

Programs developed by IPP are designed to benefit the engineering profession by:

- Raising faculty awareness of the importance of non-technical/ practice management issues.
- Producing graduates that are better prepared to enter the profession.
- Increasing young practitioner's rate of professional development.
- Reducing the firm's training costs.
- Reducing the firm's professional liability exposure.
- Upgrading the profession by causing practitioners to share their experiences with the practitioners of the future.

The Issues in Professional Practice Course

In 1992, in response to concerns voiced by practicing engineers, IPP, with support from the General Electric Fund, sponsored the development of a course called "Issues in Professional Engineering Practice." The intent of the course is to draw upon practicing engineers and allied professionals to assist engineering schools in raising the level of student awareness regarding potential significant non-technical issues in professional engineering practice. The material is also being used as an in-house training module by engineering firms to create an awareness of these critical issues among their young engineering staff.

The course materials include a bound set of lecture notes and a boxed set of reference materials, euphemistically called a "course-in-a-box". The materials are available to schools and firms wishing to implement an in-house training program.

The contents of the course-in-a-box presently includes the following:

- The Institute for Professional Practice. 1992. *Issues in Professional Engineering Practice.* Bound lecture notes and course outline.
- Bachner, J.P. 1991. *Practice Management for Design Professionals.* John Wiley & Sons.
- Culp, G. and Smith, R.A. 1992. *Managing People (Including Yourself) for the Project Success.* Van Nostrand Reinhold.
- Johnson, D.G. 1991. *Ethical Issues in Engineering.* Prentice Hall.
- ASFE. Loss Prevention Audio Tape Series. Tapes 1 through 18.
- ASFE. The Real World of Engineering" Case History Numbers 1 through 64.
- ASFE. *Contract Reference Guide.*
- Various other documents and publications.

The "Issues" course notes have been distributed to 128 practicing engineers and 321 faculty in 252 engineering programs in the United States (as well as sixteen programs in 10 foreign countries). In addition, 184 copies of a course-in-a-box have been provided to faculty in these engineering programs. The course has been implemented, in part or whole, by 178 engineering programs in this country. Of these, 43 programs are offering a full Issues course, and 32 are having the course taught entirely by practicing engineers. For more information please contract:

Daniel J. McGinley, Executive Director
Institute for Professional Practice
13 Lanning Road
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E-mail: Bridge2PE@aol.com

The Issues Course at Tufts University

As an example, the Issues course is offered at Tufts University within the Department of Civil and Environmental Engineering as a full credit elective. The course meets for twenty-six, 1 1/2 hour sessions with instruction provided or facilitated by the author. Approximately 15 senior practicing engineers and other professional are used as lecturers on various subjects which are aligned with their specific skills and expertise.

The course outline is summarized below:

Session	Topic
1	Introduction
2	Professionalism
3	Engineering Practice Organizations
4	Marketing
5	Business Development
6	Professional Engagement
7	Economics of Practice
8	Workshop - Organization Economics (CEO Role Playing)
9	Quiz No. 1
10	Professionals and the Low
11	Professional Contracts
12	Professional Risk Management
13	Alternative Dispute Resolution
14	Workshop - Contracts (Would you sign this contract?)
15	Role of the Expert Witness
16	Insurance for Design Professionals

SECTION 5

Involvement of Educators in Practice

17	Workshop - Loss Prevention (Case History discussion)
18	Quiz No. 2
19	Project Management - 1
20	Project Management - 2
21	Peer Review
22	Quality Management
23	Personnel Management
24	Technical Writing
25	Course Summary - Wrap up
26	Quiz No. 3

As can be seen, the course covers a diverse set of topics, each non-technical but significant to the delivery of engineering services. Workshops are included to involved students in discussions, teamwork, and individual and group oral presentations. Extensive outside assigned reading is required, class attendance is mandatory, written examinations and homework assignments form the basis for grading.

The course content has been adjusted somewhat from the IPP guide in order to complement other course offerings in the department and to be directly aligned with the expertise of the lecturers.

In recent years, based on course evaluation forms, the course was rated by the students number 2 out of the 34 courses offered in the department.

About the Author *— David E. Thompson is Chairman and CEO of Haley & Aldrich, Inc., in Cambridge, Massachusetts.*

Faculty in Industry: A Personal Perspective

Avery H. Demond

Why a Leave in Industry

Much has been written about the benefits to engineering education that can result from the development of closer ties with industry. In fact, the National Research Council's Board on Engineering Education (on which I served for 4 years) sees it as a key part of the process of revitalizing undergraduate engineering education (NRC 1995). Many of the innovative undergraduate curricula funded by the National Science Foundation, such as Engineering Coalition of Schools for Excellence in Education and Leadership (ECSEL), emphasize greater ties to industry.

Closer contact with industry can benefit students, faculty, and the university as a whole. For students, it may mean more opportunities to obtain co-op internships, summer and permanent jobs. Participation in co-ops often translates into higher rates of graduation because of the increase in motivation level of the students (Meade 1992b). Exposure to the problems faced by industry may result in the development of research programs by faculty geared towards the resolution of these problems. If industry perceives a direct benefit to be gained, they may be more willing to provide research grants, or enter into joint research ventures. Curricular innovations may also result from closer contact between industry and the university. Short courses may be developed by the university with an industry's needs in mind, simultaneously addressing companies' need to remain competitive through career-long learning (Girard and Kachhal 1993) and providing a source of revenue for the university. Case studies and design projects are compelling education tools (Fitzgerald 1995) which can evolve from becoming familiar with a particular company's experience.

The benefits cited above are just a sampling of those commonly given in support of a university's development of closer ties with industry. What is discussed far less often is its potential role in faculty development. How does the university insure the technical currency of a faculty member throughout his or her career? It seems that the prevailing thought is that this occurs by participating in research. But in many instances, pursuing research means staying current in a very narrow, perhaps esoteric and theoretical field. Research does not ensure the currency of industrial literacy or, the development of what Boyer (1991) referred to as "the scholarship of application." Universities seem hard-pressed to move towards a new definition of the professoriate that includes more than the "scholarship of discovery" (Meade 1992a) and have yet to tackle the issue of deliberate planning of the professional development of faculty (Anderson 1985).

Given the general acceptance of the notion that engineering education can benefit from a greater interaction with industry, the question then is how can this be accomplished? One of the most often cited means of injecting "practice" into the university environment is by hiring practitioners as adjunct faculty (Nord 1989; Kovac and Augustine 1992). By doing this, two needs may be met simultaneously: students obtain exposure to "real life" and the university fills short-term faculty openings (Locke 1989). But this approach presents a number of problems. First is the question of funding. Generally, the university cannot meet industry salaries. Thus, the university is asking the practitioner take a cut in pay, to work *pro bono*, or for his employer to subsidize the arrangement. The industry engineer who taught the undergraduate course (CEE 280 Introduction to Environmental Engineering) while I took a leave of absence to work in industry estimated that he earned less than $2.50 per hour based on the number of hours he put in and the department's compensation. Second is the question of course content. Unless the practicing engineer is hired to teach an elective, certain material must be covered. There is no guarantee that it will, in fact, be covered. When CEE 280 was taught by this adjunct, he was provided with a syllabus, textbook, lecture notes, and problem sets with answers. He chose not to use this material but to focus the course on his industrial experience. The students discussed a number of case studies illustrating the realities of engineering practice, but they did not learn the concept of mass balances. Unfortunately, in a number of subsequent courses in the Environmental and Water Resources Engineering (EWRE) curriculum at The University of Michigan, it is assumed that students learned mass balances in CEE 280 and the students who missed this material were at a decided disadvantage. Lastly, lasting systemic changes did not occur. The contact with the practicing engineer may have impacted the viewpoint of the students in that class, but there is no impact on future classes of students since the class continues to be taught with its original focus.

Alternatively, those at the university may enter practice. Students can do so through co-ops or summer jobs. The evidence (most of it is anecdotal) shows that such an experience allows a student to make the connection between the classroom and the workplace (Meade 1992b). But the impact of that experience is not felt beyond that particular student. To ensure that all students have some exposure to engineering practice, it would help if the faculty had relevant industrial experience. Some faculty come to academics from industry. For them, the question becomes one of ensuring that their industrial literacy remains current. More recently however, the increase in the time necessary to obtain a Ph.D. and the need to establish an active innovative research program to qualify for tenure means that a successful career in academics precludes spending time in industry. For faculty with this sort of background, the question is how to obtain a basic knowledge of industrial practice. How can faculty practice engineering, either to maintain their knowledge of the state of practice, or to gain some industrial exposure? The traditional means by which faculty "practice" is through consulting. Both positive and negative opinions have been voiced about the impact of faculty consulting on university education. Despite its usefulness in achieving technology transfer (Ercolano 1994) and faculty satisfaction (Eisenberg and Galanti 1981), consulting is often viewed as leading to conflicts of interest, conflicts of commitment, and the inappropriate use of university facilities for private gain (Sissom 1986; Ercolano 1994). However, many of the problems associated with part-time consulting could be resolved by a faculty member's spending a sabbatical in industry. In this scenario, the faculty would be a full-time employee of a particular company, working on the company's premises, thereby obviating issues of commitment and proper use of facilities.

Logistics of Industrial Leaves

Although a university may derive considerable benefits from a faculty spending time in industry, Kovac and Augustine (1992) note industrial sabbaticals are virtually nonexistent. The question then is why? There are problems associated with any sabbatical or leave of absence. Who will teach your courses? Advise your students? Run your research grants? If one is leaving the area, additional questions arise. Where will you live? Where will your children go to school? What are we taking with us and what are we leaving behind? But problems such as these are routinely resolve with traditional sabbaticals. There is one additional hurdle not commonly associated with traditional sabbaticals and that is the perceived value of a sabbatical in industry in the current faculty reward structure. Unless one's status in the research community is enhanced, the experience is seen as having little value, particularly with regard to tenure and promotion. When I announced my plans to spend a year in industry, I was eventually permitted to go, but many questioned the wisdom of the decision saying that I was jeopardizing my career. The question that was posed to me when I returned from my leave in industry was how many papers had I published?

Perhaps the other hurdle is that it is not clear how to make proper administrative arrangements. Since, as an untenured faculty, I was not eligible for sabbatical, I took a leave of absence from the university. It was designated a "personal leave," a category usually reserved for family emergencies, because the other choices were military service or government office. I could continue to have benefits through the university, with the exception of retirement. The difference was I had to pay for them myself. I resolved this, in part, by becoming a dependent on my husband's health and dental insurance. Thus, I was left paying for just life insurance and disability. To find an employer, I called my friends in industry. I peddled myself as an unusually capable entry-level (given my lack of industrial experience) engineer. I would work hourly with no benefits. In anticipation of spending a year in industry, I had taken the 40-hour course for Hazardous Waste Operations and Emergency Response (HAZWOPER) certification so that I already had the minimum qualifications for access to hazardous waste sites. The biggest question prospective employers asked was, "what would I do?" to which I replied, "what do you need to have done?" I accepted the offer from Geomatrix Consultants, San Francisco, CA. This firm is about 12 years old now, specializes in environmental and geotechnical consulting with about 150 employees, distributed between its main office in San Francisco and additional offices in Southern California and Sacramento.

Industrial Experience

I worked at Geomatrix for 9 1/2 months, September 1994 through mid June 1995. In all, I worked on 17 different projects, billing time to as many as 7 or 8 in a given week. Many of the assignments I received involved mostly library research with some calculations. For example, at one site groundwater needed to be withdrawn at a rate of about 2 gallons per minute to keep the water table below the zone of contamination. The question was posed whether that should be accomplished with a well, in which case provisions had to be made for the disposal of the withdrawn water. Or could this be accomplished by planting trees and if so, what type and how many trees were needed? My task was to answer that question. Off I went to the library to look for typical evapotranspiration rates for trees that were somewhat salt tolerant since they would be growing near San Francisco Bay. I also looked for pan evaporation, wind, solar insolation, and soil data in an effort to answer that question. After I picked out several types of trees which I thought were suitable, I called commercial nurseries recommended to me by a friend in the landscaping business to see what their opinion was of my choices, to get information on maintenance, and to get prices. The only question I had difficulty resolving was whether or not the type of tree selected could tolerate the levels of arsenic that were present at the site.

Most of the projects I worked on had little to do with my expertise in subsurface organic liquid movement. I designed air-stripping towers (in series to blend in with a residential setting; operated at elevated temperatures for the removal of acetone) and wrote protocol documents so that junior engineers could do likewise. I designed carbon adsorption units to treat vapors from air stripping towers. I developed a spreadsheet to allow them to calculate competitive sorption of one organic compound in the presence of water vapor, or in the presence of additional organic compounds (up to 9 compounds). Using this program, I demonstrated to them that it was generally more economic to elevate the temperature of off-gas from air stripping towers to lower the relative humidity than to passing it over carbon adsorption beds directly. I wrote reports summarizing the treatment technology options for the removal of dilute hexavalent chromium and trichloroethylene (TCE) from groundwater.

I guess the biggest stir I created was a report I wrote comparing the characteristics of a client's site contaminated with TCE with other sites contaminated with TCE. It was based on the report issued by National Research Council, "Alternatives for Ground Water Cleanup" (NRC 1994). I was a reviewer of the report and so I was aware of it, but it had not yet reached the general attention of the consulting community. Based on the comparison between the client's and other TCE-contaminated sites, I concluded that the remedial action plan for the target site, which was based primarily on pump and treat, would never achieve the clean-up goals (set at a TCE concentration of 5 micrograms/L), and could only serve to contain the central mass of the plume.

Benefits

I enjoyed my time at Geomatrix. I enjoyed working with professionals. I enjoyed working in an organization where workloads are adjusted to achieve a reasonable work week. I enjoyed working in an organization where if your computer was acting up, another was on your desk within an hour or two! I enjoyed working in an organization which appreciated my efforts. Although I did not increase my technical knowledge in the subject areas that I teach or do research in, I did learn things that are less tangible. The experience affirmed my conviction that what I was teaching students was appropriate; that the concepts and problem-solving strategies we covered in class would help them in engineering practice. (If only they could remember what we discussed after the conclusion of the semester!) I altered my approach somewhat to emphasize the integration of concepts. Students in CEE 280 now receive homework in which they essentially have to go through the calculations necessary for the filing of an air emissions permit for a vacuum extraction/combustion engine that is to be installed to remediate a subsurface gasoline spills. This problem requires them to combine information covered in different sections of the course:

emissions factors, dispersion of air-borne contaminants, and health risks from inhalation of carcinogens. Based on the feedback, I discovered that this integrative approach causes general panic. Many students said they had thought they knew what was going on in the course, but apparently they did not. Others (the good students) said it caused them to pause and think. Since any real-life problem will require pulling information from a number of sources, the students need to learn this skill. My graduate level class, CEE 593 Environmental Soil Physics, has always emphasized analytic solutions to subsurface transport equations, with the thought that time is often critical and ball-park answers are frequently all that are needed in engineering practice. My experience at Geomatrix affirmed that approach. Now, in addition, the students receive problems in which data are very limited, since this situation seems to be the rule rather than the exception. For example, "What is the inhalation exposure to a worker walking on the soil surface at a site in Ann Arbor, Michigan where there is rumored to be a subsurface spill of TCE?" (This is the complete problem statement.)

The experience also stimulated me to become a licensed professional engineer. Blueprints and many other documents had to be signed off on by either licensed engineers or geologists. It was apparent that status in the company was based, to some extent, on the number and types of certification one had. I also realized that obtaining licensure could increase the value of my having spent time in industry in the eyes of my some of my colleagues.

Conclusion

Taking a leave to work in industry is one of a number of means that closer ties between industry and academics can be achieved. Although industrial leaves appear to be fairly uncommon, they resolve a number of the problems associated with the hiring of practitioners as faculty or part-time consulting by faculty as methods of introducing practice into the engineering curriculum. The major obstacle to faculty spending time in industry is the perceived lack of value towards one's career. With changes in the faculty reward status imminent (Meade 1992a; NRC 1995), perhaps the spending time in industry as a means of developing one's "scholarship of application" will become more acceptable. Certainly, with the increased downsizing and outsourcing that is being practiced by many American companies, the skills of faculty can be put to use in the workplace!

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Faculty as Adjunct Practitioners

Dee Ann Sanders

Introduction

Engineering faculty have a long history of practicing their craft. Universities, sometimes formally and sometimes informally, have encouraged faculty to consult by providing time during the academic year. Summer assignments with industry have been common for engineering faculty. Faculty who work in practice usually report that it is a beneficial part of their professional life. However, an engineering faculty assignment is a full-time (or more) load, especially for new faculty working toward tenure. Consulting will take time away from teaching, research, service, or a faculty member's scarce personal time. Should environmental engineering faculty work in practice? Why? What are the benefits? What types of practice-oriented problems do faculty members address? What are the problems? How does a new faculty member get started? How does an individual decide whether to perform work outside the teaching/research/service paradigm? Finally, what does the future hold for the faculty practitioner?

Goals of Environmental Engineering Education

The literature strongly supports the inclusion of practical problems into environmental engineering education. Prior to the last half of this century, environmental engineering education was heavily practice-oriented (Pohland and Anderson 1996). At a meeting at the University of Maine in 1927, the Board of Investigation and Coordination of the Society for the Promotion of Engineering Education (predecessor of American Society for Engineering Education) concluded that:

> "Experience indicates clearly that it is bad for morale to delay too long the adjustment to practical life or to make the transition from a highly intellectual type of college program to a necessarily rudimentary experience too violent." (ASEE 1927)

Many of the skills and attributes of the new engineering graduate come from an exposure to practical engineering problems. A partial list of these skills and attributes. gathered from several sources (AAEE/AAEP 1991; Aldridge 1994; ASEE 1992; ASEE 1995; Baillod 1986; Pohland and Anderson 1996; Schwartz 1991) includes:

- An ability to apply knowledge to the conception, analysis and design of solutions to real-world environmental problems
- Skills in written and oral communications
- An ability to implement technology-based solutions to environmental problems through design, construction, and operation
- The ability to work in diverse, multi-disciplinary teams
- The ability to make trade-offs, especially for economic reasons
- Knowledge of current environmental regulations
- Skills in time management (to survive the intense pressure of real-world budgets and schedules)
- The discipline to support life-long learning.

While many of the attributes outlined above can be fostered in a traditional, theory-based environmental engineering education, the inclusion of experience from professional practice is strongly supported by engineering educators and practitioners. Professional practice has been defined by Aldridge (1994) as "The act of working first-hand with situations for customers by using a combination of highly-specialized knowledge and skills that are obtained through study, training, and experience." Faculty practitioners can bring case studies from their own experience into the classroom to reinforce the communication and problem-solving skills required of today's new engineers. Experience with the multi-disciplinary teams used for large consulting projects help the faculty member guide student teams through design projects. Faculty who have performed trouble-shooting on environmental systems can teach students the importance of operations and maintenance considerations in their designs.

Engineering faculty who obtain industrial experience prior to beginning their academic career have been shown to have strong commitments to teaching (Fairweather and Paulson 1996), as evidenced by spending more time than required on teaching and teaching more undergraduate classes. Prados (1996) underscores the need for changes in engineering education culture to prepare students for the 21st century. These changes, which are consistent with an increasing emphasis on practice by faculty members, will result in engineering scholarship that is "integrative, team-based, cross-disciplinary, and educationally-focused."

Practitioner's Perspectives on Industry/ Faculty Relationships

The cultures of practice and academia are very different. H.G. Schwartz, in his address to the Sixth Environmental Engineering Conference (1991) referred to this as "the bozos versus the eggheads." Faculty, especially new faculty or those with little practical experience, tend to think of those in practice as somehow inferior intellectually. Practitioners think professors are too theoretical to be trusted outside the laboratory. Leake (1993) reports that faculty/practitioner interactions "sometimes seem like partners bound together in a three-legged race." The different goals of academe (the pursuit of knowledge and support of graduate students) and of practice (gaining a competitive edge in developing new technologies), can result in problems. The solution, according to the authors, is close cooperation and a clear understanding of the goals of each party and of the project.

University Perspectives on Practical Engineering Experience

A very real problem with faculty consulting is the lack of support by the academic community. Despite the history of engineering as a practice-oriented profession, and despite the faculty release time for consulting provided at some universities, prestigious (i.e., research-oriented) universities seldom encourage consulting or other practice-oriented work through the formal reward structure. An even greater problem is the informal reward structure, or "faculty culture," as addressed by Fairweather and Paulson (1996). Universities appear increasingly to fill new positions with faculty lacking industrial experience. New faculty realize very quickly that research is the path to tenure and the respect of their peers. Practical experience is not. This trend will result in even less emphasis on outside experience as new faculty members replace older ones who had practical engineering experience. According to the research, this trend will adversely affect engineering teaching.

Engineering Faculty Experiences as Adjunct Practitioners

A review of the literature generally supports the role of engineering faculty in practice. Any negative impacts fall upon the faculty member, seldom on the student or the university. The experiences of the author, based upon sixteen years in consulting, government, and industry prior to beginning an academic career, also generally support the value of engineering practice. To gain additional insights into the positive and negative experiences of the adjunct practitioner, current engineering faculty were polled by informal survey. A brief questionnaire was sent by electronic mail to 86 faculty members registered for an AAEE/AEEP conference. Faculty were asked whether they performed outside work, such as consulting. Those who did not, or had not yet, worked in practice were asked why. Faculty who worked in practice were asked

- What types of projects they performed
- How they selected/were selected for the projects
- Whether they were satisfied with the results of the projects.

These questions, asked from the practitioner's perspective, were also posed to eleven upper-level engineering managers and executives who use engineering faculty in their practice.

The survey questions were formulated to answer the research questions of

- Why do environmental engineering faculty work in practice?
- What types of activities, and on what types of projects, do faculty work in practice?

- What are the problems for faculty who work in practice?
- How satisfied is the practitioner client with the faculty practitioner?
- How can a new faculty member begin a career as an adjunct practitioner?

Thirty eight faculty members responded to the questionnaire. Results of their responses and the nine responses from practitioners are discussed below.

Why Do Faculty Work in Engineering Practice?

Why should a busy faculty member perform consulting or other outside activities? The literature previously cited and common reflection show that, to educate the engineer (who will be a practicing professional), faculty members should have some knowledge of practical engineering problems. Many sources (Pohland and Anderson 1996; Schwartz 1991; Baillod 1986; Panitz 1995) recommend the use of adjuncts, industrial mentors, or "practitioners in residence." While practitioners who act as adjunct faculty will benefit the student, faculty who consult or otherwise work in practice are a very valuable asset to the student and the university. Practice also benefits the faculty member.

Faculty attendees at the conference who responded to the questionnaire sent by electronic mail reported that consulting was beneficial to their teaching and research. Faculty reported that consulting gave them new ideas for research, added practical examples for teaching, and gave a sense of satisfaction that comes from seeing new findings applied to practical problems. Relationships with consulting firms and industry also allow faculty members to help students find jobs upon graduation. Most engineers can remember (if somewhat murkily), their undergraduate days. The professor who provided lively examples of engineering practice was the professor who kept the students awake, made them enthusiastic about their choice of a demanding profession, and sometimes even kept them in school. Faculty owe it to the profession to carry this tradition forward. Besides, it's fun! It is tremendously gratifying to see students actively involved in a class, especially when the class is a required one outside the students' main interest (such as an introductory environmental course for civil engineering students).

Environmental engineering faculty provide a very valuable service to consulting firms and the public when they apply their specialized knowledge and skills to problems beyond the capability of consultants, public employees, and others. Most faculty members who consult are very careful to limit their consulting to highly specialized problems in their area of expertise. Several were very careful to point out that they did not compete with the private sector.

University professors have great credibility with the general public. The input of faculty members is frequently sought because professor's opinions are seen as totally objective and lacking financial incentive. Because the practice of environmental engineering so often involves contentious public interaction, the credibility provided by a professor can determine whether a project goes forward or is cancelled.

Types of Activities and Types of Projects of Faculty Practitioners

Faculty who practice engineering outside the university walls try to select projects that are exciting, use their specialized knowledge, and provide new ideas for research and teaching. Most faculty practitioners reported that they provide specialty consulting to consulting firms. The most commonly cited task was some form of treatability study or trouble-shooting. The consulting firms with which faculty worked usually lacked expertise in the area of the faculty member. Faculty at universities in remote areas can be the only reasonable source of consulting activities in their area. As stated earlier, faculty must be careful to avoid competition with practicing engineers, but most report that this is possible.

Faculty performing summer projects can be involved in applied research. Government agencies, such as the Department of Energy (DOE), the Department of Defense (DoD), the United States Environmental Protection Agency (EPA), and the National Science Foundation (NSF) sponsor faculty research sabbaticals. The sponsors consider this work to be research. However, much of the research is of an applied nature and helps the faculty member keep up with changes in practice.

Expert services, such as expert witness testimony, is a valuable product we provide for the practicing world. Many professors reported that they have provided expert services to attorneys. Most faculty serving as expert witnesses are more senior and widely-known, but a surprisingly large number of junior faculty have also provided expert services to attorneys.

Potential Problems with Faculty Consulting

Consulting takes time. It can take a great deal of time. Consulting schedules are usually tight, often unpredictable, and virtually never align neatly with an academic schedule. Several faculty members reported that they did not consult, consulted infrequently, or regretted consulting. They said that the time required, and the unforgiving schedules, were problematic. As discussed in the next section, engineering practitioners also report that schedules are the biggest problem for faculty members who work with them.

Working with practitioners can be frustrating, especially for new faculty members who lack practical experience. Neither faculty nor practitioners benefit from this culture war, and it certainly does a poor service to engineering students. Mutual understanding and respect are needed. The faculty member who thinks most students will eventually be "bozos" is a poor role model. In addition, the climate for research funding is changing. The faculty member who refuses to perform applied research (such as industrial consulting) will find support increasingly difficult to obtain (Likens 1995).

Consulting by faculty can be seen as competition with private practice. After all, a primary product of the academic institution is the engineering student, who will go to work for a consulting firm upon graduation. State institutions are especially careful to discourage faculty members performing projects in competition with practicing engineers.

A few faculty expressed dissatisfaction with other aspects of working in practice. Two cited slow payment for work performed; other faculty pointed out that they avoided such problems by being very careful about accepting projects. Some faculty said they were frustrated that their work was not accepted for political reasons. This is also a problem for consultants; it is not unique to faculty practitioners. Disagreements over scope were also fairly common. Again, many of the problems with a practical project can be avoided by being careful and thorough in initial negotiations with the client.

Industry's View of Faculty Practitioners

The opinion of those in industry depends upon whom you ask and how you phrase the question. All the industrial people contacted reported that they were very much in favor of industry-faculty relationships. They said that interactions with faculty provided fresh views toward problems, helped keep their technical people in touch with new and theoretical work, and maintained important liaisons with faculty and universities. Several stated that faculty provided credibility when they dealt with the public.

However, the problems of schedule and responsiveness were troubling to the industrial people. Several practitioners stated that faculty are non-responsive to consultant's and client's schedules. Consultants realize that faculty have many demands upon their time, but consulting projects are heavily cost and schedule-driven, often by regulatory mandate or compliance orders, so faculty inability to meet schedules is a serious problem. The practitioner-client may understand that a graduate student thesis takes time, but he does not have the flexibility to wait two years for a final report.

Faculty are also seen as putting their own projects ahead of those of the consultant. This takes the form of schedule conflicts, as previously discussed, as well as changing the scope of projects to meet the faculty member' s research priorities. Some consultants were also distressed that faculty used the consultant's projects as "graduate student full-employment programs," even when the faculty member was clearly selected because of his/her own expertise and reputation. The single-minded pursuit of theoretical research over a client's need for a quick and economical solution has cost faculty members consulting jobs. A senior manager with a large consulting firm warns faculty to never use words such as "research," "study," or "experiment" in meetings with clients. The author's experience from practice also reinforces this recommendation. The faculty practitioner must always work toward the client's goals, subjugating her own when necessary. Again, faculty should only work on projects that will interest or benefit them professionally, so that the tendency to change the project scope is minimized.

Three practitioners, all managers within federal agencies, stated that a major, recurring problem in dealings with engineering faculty relate to bureaucracies: theirs or the university's. One manager said that university bureaucracies were slow and unwieldy as compared to the government. The other two said their problems related to the inability of faculty to negotiate the federal bureaucracy. A manager with EPA said that some faculty had attempted to "shake up the bureaucracy," to the detriment of the faculty member and the project. Faculty members working with him had found and advertised loop-holes within federal regulations, resulting in the closing forever of the loop-holes. The other manager said that faculty members expected access to secure areas with no notice, which indicated a lack of appreciation of the federal bureaucracy.

Despite the problems, far-sighted practitioners realize the value of faculty practitioners. Faculty members who select projects of interest to them and with clearly defined and understood goals, are well received by those in practice. There will always be a role for faculty practitioners, and those in practice realize this.

Initiating a Career as an Adjunct Practitioner

It is difficult and frustrating for new faculty to gain experience and exposure, but experience and exposure are necessary to be sought for meaningful consulting projects. The best way to get exposure, according to both faculty and the practitioners who use them, is to publish the results of solid, practical research. Potential clients are often highly educated and are active in professional societies such as the Water Environment Federation, American Water Works Association, American Academy of Environmental Engineers, and the American Society of Civil Engineers. The publications of these organizations are read by those who employ faculty consultants. Faculty who want to be recognized by practitioners should publish in them. Practical, applied research is of paramount concern to consulting firms. Theoretical research will probably not result in extensive consulting, at least not for faculty who have not yet achieved national reputation. Publishing survey papers (literature reviews) can also result in positive exposure for new faculty members.

All the engineering practitioners recommended that new faculty attend as many meetings, seminars, and symposia as possible. This is also supported by the literature (ASEE 1994). Faculty should actively participate, seeking out practitioners and discussing interests and common ground. Practitioners also recommended that engineering faculty invite outside engineers to seminars (such as the graduate student seminars common at many universities). Teaching at urban university branches, where practitioners take night courses, is also a way for faculty to get exposure to members of practice. As surely as engineering students need communication skills to survive, new faculty need communication skills to get the attention of the practitioners who can provide future projects.

It pays to advertise. While faculty with national reputations do not need to advertise to get consulting work, new faculty may benefit from advertising their services. A practical way to do this is through the Internet. A partner with a major environmental engineering firm said her company uses a service that finds faculty practitioners through the Internet. The potential faculty practitioner can also find opportunities through the Internet. Some consulting firms and most governmental agencies that use engineering faculty advertise their programs through their Internet pages.

A more traditional approach to advertising is through routine professional interactions. A faculty member interested in consulting should let practitioners know, when talking to them at meetings or symposia, that the faculty member enjoys the challenges and tight schedules of real-world problems.

A Look to the Future

What changes do faculty and practitioners see for the adjunct practitioner? The downsizing and outsourcing common in business is beginning to extend to engineering consulting firms. This trend will benefit the faculty practitioner, as long as he/she is also willing to adhere to the tighter schedules and costs that also appear to be the trend within consulting. Continuing education is a strong trend for the practitioner; this will benefit the faculty member resourceful enough to make professional contacts at continuing education programs. A few sources (Pohland and Anderson 1996; Schwartz 1991) recommend that business and industry exchange their practitioners in the future. Probably the only thing certain is change, but change usually benefits the resourceful.

Conclusions and Recommendations

Working as a faculty practitioner is time-consuming and immensely rewarding. It results in better teaching and research. Faculty practitioners provide a valuable service to the profession and the public. What few problems result from faculty-practice relationships can usually be avoided by both the faculty member and the practitioner-client being completely candid about the project and its goals. While adjunct practitioners will never be exactly equivalent to full-time practitioners (any more than adjunct faculty are exactly equivalent to tenured faculty), practicing the art and science of environmental engineering is so valuable personally and professionally that it is highly recommended. Dr. Edward J. Bouwer (1996) summarized the value of engineering practice as follows:

> I have benefited greatly from the consulting (outside academia) work. The consulting projects have given me great examples to use in class. The exposure to practical problems has allowed me to focus my research to be more relevant to the issues in the field. I have also established many contacts with industry and consulting firms which helps me to locate jobs for our graduates.
>
> The consulting work has also been a benefit to my 'psyche.' I get a sense of pride from giving expert advice and knowing that I am accomplishing something good. The consulting work is generally 'my own,' so it gives me a chance to use my knowledge directly to help the engineering community.

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SECTION 6

Outcomes Assessment

Licensing and Specialty Certification: Methods for Outcomes Assessment

William C. Anderson

Introduction

Engineering education in the U.S. became well established by the early 1900s. Since then, it has been the subject of countless studies. The "Wickenden Report" of 1930 (SPEE 1930), the two "Hammond Reports" — *Aims and Scope of Engineering Curricula* (SPEE 1940) and *Engineering Education After the War* (SPEE 1940), the "Grinter Report" of 1955 (ASEE 1955), and the 1985 report of the National Research Council's Committee on the Education and Civilization of the Engineer [The "Haddad Report" (NRC 1985)] were all landmark studies of the past. Recently, the National Research Council's Board on Engineering Education issued a report — Engineering Education: Designing an Adaptive System (NRC 1995). What is startling about all of these studies is the consistency of their recommendations:

- the need for strong grounding in the fundamentals of mathematics and the physical and engineering sciences;
- the importance of design and laboratory experimentation;
- a call for more attention to the development of communication and social skills in engineers;
- the integration of social and economic studies and liberal arts into the curriculum;
- the vital importance of good teaching and attention to curricula development; and
- the need to prepare students for lifelong learning (NRC 1995).

The Board on Engineering Education recommendation that the Accreditation Board for Engineering and Technology (ABET) adopt measurable performance or output-oriented accreditation criteria (NRC 1995) is on the path to becoming reality. ABET's Criteria 2000 approach to accreditation with is reliance on outcomes assessment represents a "leap-of-faith" of historic proportions. Abandoning its focus on inputs, which has, arguably, performed well for over a half century for a system which allows universities to set their own agenda is risk-taking on a grand scale, given the number of engineering programs. There are currently over 300 institutions that grant B.S. engineering degrees or higher in accredited programs. This group incorporates not only the 150 or so research universities and doctorate-granting institutions, but also 160 plus other institutions that focus primarily on undergraduate education and which produce nearly a third of the nation's engineers (National Science Board 1993).

ABET's new approach to accreditation is intended to promote creativity and innovation in education and foster diversity enabling each engineering college to do what it does best or what it wants to do best. Given the multiple environmental engineering specialties and concerns, institutions and faculty should wholeheartedly embrace this opportunity. At the same time, they must also be mindful of the needs of employers and students, the customers of the education enterprise — there must be accountability.

The problem confronting institutions is not the paucity of outcomes measures, but their plethora and the varying degrees of acceptance in the marketplace. Some of these measures include:

- standard assessment measures — Fundamentals of Engineering (FE) exam; Graduate Records Exam (GRE); Principles and Practice of Engineering (PE) exam; and specialty certification exams;
- Capstone Design Courses;
- Teacher evaluations — student-based evaluations of teaching effectiveness;
- Alumni achievement/satisfaction — graduate evaluations of how well the institutions prepared them for their careers;

- Career-services interaction — feedback from employers and other demographics compiled by the institution's placement office; and
- Intern evaluations — feedback provided by supervisors of students involved in intern and co-op programs (Bakos, 1996)

Others (Grigg 1995; Kerkes 1995; and Wilson 1995) suggest that integration of practicing professionals as part-time teaching faculty offers yet another opportunity to assess a program's effectiveness on a continuum as part of their interaction with students and full-time faculty. Of all of the outcomes assessment methods, the standard examinations are the most objective.

The Medical Profession's Experience

Medical education has employed outcomes assessments since 1906 (Martini 1989). However, more recently the oversight of medical care by the Health Care Financing Administration (HCFA) beginning in the early 1980s and the concerns of HMOs have added real-world business pressures that focus renewed emphasis on the quality of medical care and, as a consequence, medical education. Additionally, the U.S. Secretary of Education [(Federal Register, 53 (July 1, 1988):25088-25099)] requires postsecondary accrediting agencies to evaluate educational effectiveness by determining that postsecondary institutions and programs document the educational achievement of their medical students — in light of the degree awarded — in verifiable and consistent ways, including the scoring on licensing examinations (Kassebaum 1990).

As a result of these various pressures, medical education is grappling with integrating old and new methods of outcomes assessments into a system enabling a comprehensive judgment about a program's quality. This experience provides valuable guidance for engineering education. The task is judged to be somewhat simpler for medical education than for engineering education because of a historical familiarity with numerous outcomes measurements of student achievement including licensing examinations, selection for specialty education, specialty certification, and observation of clinical performance, to name but a few. Table 18-1 presents typical medical school goals and outcome measures (Kassebaum 1990). It should be noted that these are not much different than those suggested for engineering, as summarized earlier.

Donabedian (1988) identified the key to using outcomes assessments is definition of program goals. It is the goals established by the program which determine the type of assessment methods to be employed. For example, the expressed goal of engineering education for a strong grounding in the fundamentals of mathematics and the physical and engineering sciences can be determined by the use of the Fundamentals Examination (FE).

However, the goal of communication and social skills relates to the interpersonal skills of the engineer which the FE exam is ill-suited to measure. These skills can be better measured by other techniques, such as surveys of employers.

It is a natural tendency, particularly for the laity, to assess quality in medicine using ultimate measures, such as patient satisfaction and mortality. However, these ultimate measures of medical performance are affected by many factors beyond the control of medical education (Donabedian 1988). Similarly, a common complaint of those opposing engineering licensing is that the license does not guarantee quality engineering. However, those complaints are as misguided as those expecting all licensed physicians to have a high degree of patient satisfaction and low mortalities associated with the delivery of their services. Engineering credentials are specifically designed to identify those who have the *minimum* competence to offer their service to the public or, in the case of specialty certification, to represent to the public that they are expert in a particular specialty.

Licensing And Specialty Certification

This paper advocates the use of licensing and specialty certification as outcomes measures which can and should be embraced by environmental engineering programs. However, it is not suggested that they be the *only* measures, but rather part of an integrated system. Licensing and specialty certification offer advantages to institutions as outcomes measures. They also have disadvantages under current conditions.

Background

As indicated by the experience in medicine, program goals and the methods employed to assess outcomes are inextricably linked. Therefore, it is appropriate to examine the origins of one of these measures, the relatively new (1993) P.E. examination for environmental

Table 18-1
Typical Medical School Goals and Corresponding Outcome Measures or Indicators

Goals	Outcome Measures or Indicators
Enrollment	
Admit qualified applicants with capacity to benefit from program	• Premedical GPAs, MCAT scores, non-test attributes • Medical school course performance • National achievement test (NBME I) • Academic difficulty and graduation rates
Establish racial diversity	• Enrollment records
Educational	
Provide strong basic science grounding	• Basic science course performance • National achievement test (NBME I) • Clerkship, elective and residency evaluation of basic science grounding
Develop exemplary clinical knowledge and skills	• Clerkship and elective evaluations (narrative observations, course performance, NBME II subject examinations) • Clinical skills assessment (patient simulations, OSCEs, performance with management problems) • National achievement test (NBME II)
Develop professional attitudes	• Narrative and test (simulations) evaluations by faculty, residents, and patients
Develop close student-faculty interaction	• Student surveys • Course evaluations • AAMC graduation questionnaire results
Prepare students for success in graduate medical education	• Residency match results • Knowledge and clinical skills performance of residence • In-training specialty board test performance • Specialty certification
Career and Practice	
Foster career choices in needed/underrepresented (e.g., primary care) medical specialties	• Medical specialty choices of graduates • AAMC/AMA graduate education tracking
Assure qualification for licensure	• NBME III or FLEX results • Licensure results
Encourage practice settings in underserved areas	• Practice location of graduates
Renew academic resources	• Academic/research appointments

Abbreviations: GPA - Grade-point average; MCAT = Medical College Admission Test; NBME = National Board of Medical Examiners tests Part I, Part II, and Part III examinations); OSCE = objective structures clinical examination; FLEX = Federation Licensing Examination engineering. This examination came into existence as a result of demands from state licensing boards, themselves a reflection of demands by engineers seeking licensure, that the National Council for Examiners of Engineering and Surveying (NCEES) provide an examination specifically designed for environmental engineers to augment the civil engineering examination with its several environmental-related questions and the chemical and mechanical engineering examinations with a few environmental engineering test items.

Prior to this request, NCEES had completed a Professional Activities and Requirements (PAR) Analysis. This analysis, done by discipline, queried individuals practicing at the entry level (0-6 years post-licensure) (Herndon 1993). It provided the essential data which all engineering disciplines, including environmental engineers, have employed to define the scope of the discipline-specific P.E. examinations.

The environmental engineering P.E. examination scope, which reflects actual engineering practice as defined by the PAR Analysis, includes two test items on water supply, two on wastewater, one on air pollution control, one on solid or hazardous waste management, and two on health, safety, and environmental protection. As this scope indicates, modern environmental engineering practice remains dominated by water-related concerns. Air pollution control and solid and hazardous waste management are smaller concerns. As distinct specialties, health and safety are smaller still, yet the examination devotes 25 percent of its content to these issues and environmental protection because they are an integral part, in one way or another, of every other facet of environmental engineering practice. This development of the examination scope has been and continues to be misunderstood by those who criticize it as too broad or encompassing subjects which many educational programs do not address. For more details on the development of the environmental engineering examination, see Herndon (1993).

Similarly, both the written and oral examinations used by the American Academy of Environmental Engineers for specialty certification are developed and tested by licensed environmental engineers with experience and proven capability in an area encompassed by each of the seven specialties for which certification is granted. This development process and the associated two-year recurring Examination Results Evaluation and Content Updating ensures that these examinations are representative of contemporary practice within each specialty.

Both the P.E. and specialty certifications examinations are based on the concept of defining whether the individual possesses minimum c*ompetence*. In the case of the P.E. examination, this means that those passing the examination possess "the lowest level of knowledge at which a person can practice professional engineering in such a manner that will safeguard life, health, and property and promote the public welfare," (Herndon 1993). For the specialty certification examinations, it is the lowest level of knowledge at which a person can represent to the public that they are expert in a subject area, e.g., air pollution control.

Advantages

The advantages of licensing and specialty certification examinations as outcomes measures are many:

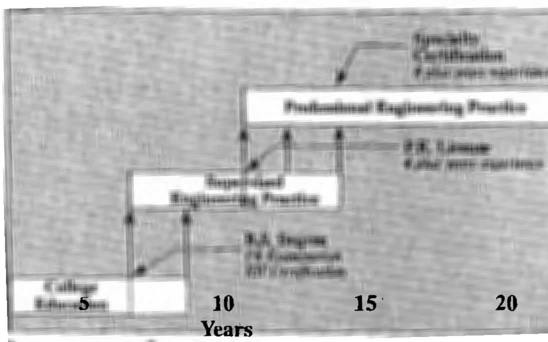
FOR THE PROGRAM

- They require little effort by the program or institution to apply.
- Statistical data are easily captured and analyzed.
- They are defined by practitioners based on conditions under which most environmental engineers work.
- They are objective measures and, most importantly, are perceived to be objective measures.
- They provide motivation for the student to pursue lifelong learning and development, a long-subscribed goal of engineering education (see Figure 18-1).

FOR THE STUDENT

- They provide credentials that will benefit each individual throughout his/her career by enhancing bargaining power and increasing career options (Likens 1996).
- They provide motivation for lifelong learning.
- They enhance the individual's status within the profession.

Figure 18-1
Typical Environmental Engineering Career Development and Associated Milestones



FOR EMPLOYERS

- They provide a measure by which business and industry can establish that they have employed properly-qualified engineers (Likens 1996).

FOR THE PUBLIC

- They assure the public that engineers have demonstrated minimum competence and have placed the public's health, safety, and protection as their primary concern.

Disadvantages

Medical licensing examinations, National Board of Medical Examiners (NBME) Part I, which assesses knowledge of basic medical sciences, and Part II, which evaluates clinical science knowledge, have a certain equivalence to the Fundamentals of Engineering FE examination for engineers, particularly in its proposed form. The NBME Part III examination, which evaluates clinical knowledge and patient management skills, is somewhat comparable to the P.E. Examination. Studies of the NMBE examinations by Jones et al. (1986) and Turner et al. (1987) have identified certain failings which must be considered when used as outcome measures to assess the quality of education programs. Some of these shortcomings include:

- they do not account for varying admission standards;
- performance can be enhanced by special preparation outside the education provided by the curriculum; and
- school policies on the examinations can affect results.

The examinations are not necessarily effective predictors of competent practice, in part, because there is no agreement on what constitutes "professional competence" (Martini 1989). However, the studies by Turner et al. (1987) indicate that a significant correlation exists between scores on each of the three parts of NBME Examinations and ratings on the cognitive aspects of postgraduate clinical competence.

Motivation to take and successfully complete the licensing examinations, while not a problem in medicine, given the requirement that all physicians be licensed, is a significant factor in the use of the licensure examinations to assess outcomes in engineering education. For years, the U.S. Coast Guard Academy required its students to take the FE examination. Although the Coast Guard Academy selects its students from the top tier of high school graduates throughout the United States, and its engineering programs are ABET-accredited, its collective pass rate on the examination lagged national averages. According to Mazurek (1995), the Academy concluded, as a result of a comprehensive study, that this occurred because the students were not motivated to succeed on the examination. They also found that faculty did not inform the students regarding the examination in a timely manner or of its content. Motivation is not only important for the FE examination, but is critical to the success of other facets of engineering education (Kuhn and Vaught-Alexander 1994; Mickelborough and Wareham 1994), and therefore contributes to higher ratings in other outcomes measures.

Conclusions

The experience with outcomes assessment in medical education has demonstrated the need to employ several methods to effectively determine if an educational program is providing its students with the attributes necessary for success in practice. Of the many techniques available, licensing and specialty certification examinations can determine if students have acquired the essential scientific knowledge and the skill to apply that knowledge to practical situations; a primary reason for formal education. But, as noted by Donabedian (1988), such examinations cannot measure other attributes education is expected to impart such as communication skills, client satisfaction, and other factors related to the delivery of service. Nor are such examinations guarantors of performance. It is concluded that these findings in medicine are directly applicable to engineering.

With the real and perceived objectivity of examinations, the FE, P.E., and specialty certification examinations provide credible proof to employers and the public alike that those they entrust to exercise the power of engineering knowledge have demonstrated competence. Yet, it is universally held that universities cannot provide all the knowledge an engineer should possess in the limited four plus years available, and ensuring lifelong learning has been problematic. Nevertheless these examinations could provide the essential motivation for the graduate engineer to embrace lifelong learning if they were universally-accepted and used by the university and the marketplace.

The findings of Mazurek (1995) augment the author's own observations that motivation of students is key if licensing and specialty certification examinations are to be employed by the program as outcomes measures. Without timely information about the examinations, their content, and importance of the individual's career opportunities by a supportive faculty, students will not be motivated to succeed on the examinations and thereby comprise their use as an outcomes measure. Those who could complain that the examinations cannot be used because they cover more subjects than curricula address are reminded that the examinations are based on the actual experience of their graduates as determined by the NCEES PAR Analysis of what is expected of those who practice environmental engineering.

Motivation is also the responsibility of the marketplace. Continued professional development, an essential element of an engineer's education, can only prosper with support by employers and market conditions. This is true for all facets, not just credentials. If the engineering marketplace embraced credentials as does medicine, the current disadvantage, lack of individual motivation, would cease to exist.

Recommendations

The university education of an environmental engineer is just the beginning. But, it is a major determinant of what follows and this is what the Criteria 2000 program hopes to ensure by its emphasis on outcomes. Medical education has proven the viability of licensing and specialty certification examinations as effective outcomes measures of cognitive aspects of postgraduate clinical competence. Because of their similarity to the examinations used in medicine, it is recommended that licensing and specialty certification examinations be adopted by environmental engineering education programs as two of a series of outcome measures to validate the quality of the education provided and to satisfy ABET accreditation requirements. To ensure the effectiveness of these examinations, it is important to appropriately match their measurement capabilities to program goals. Not only can they measure education quality, they can provide multiple, lasting benefits for the public, employers, students, and faculty.

Experience has demonstrated the need for motivation for individuals to succeed in licensing and specialty certification examinations. If faculty embrace these examinations as a measure of program success, performance on other outcome measures will benefit as well. An equally important source of motivation is the market; employers must assume responsibility for encouraging continuing professional development by systemically employing licensing and certification as benchmarks for promotion in engineering careers. Universally embraced, these examinations have the potential to engage the individual, the university, and the employer in a joint enterprise for better-educated environmental engineers.

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Outcomes Assessment: A Faculty Perspective on its Present Status and Likely Future

Trudy W. Banta

The University of Queensland Australia, recently hosted the eighth in a series of annual international conferences on assessing quality in higher education. The conference attracted representatives from 35 countries all around the world: the United Kingdom and Europe, Asia and Africa, North and South America.

It will not surprise the reader to learn that the same concerns we hear voiced about higher education in America are echoed around the globe, such as

- Increasing numbers and diversity of students that are forcing us to teach differently and worry more about what students are learning.
- Rapidly rising costs without hope of resource increases to match.
- Public expectations that higher education will produce a workforce that can compete in a global marketplace. (And this particular issue seems to be resulting in a devaluing of higher education's historical role as an important source of scholars responsible for producing NEW knowledge.)

Since the 1960s we have been asking social service agencies and public schools for evidence of their accountability for the use of taxpayer funds. But until the 1980s we in the ivory tower were considered immune from probing questions about our effectiveness. This is no longer the case.

Public dollars must be spread over an increasing number of services, and prisons, highways, and Medicare present more immediate, pressing needs than does higher education. In fact, higher education is coming to be viewed more as a *private* good — to be paid for by individuals — than as a public imperative.

Competition for higher education comes not just from other service agencies but also from within the education sector itself. Our colleagues in Europe, where the number of significant higher education institutions in any given country can be described in terms of scores, are incredulous when we report that the number of colleges and universities in the United States is over 3,500. We may be overbuilt!

Moreover, internal corporate training programs and hundreds of private training firms are vying for our bread-and-butter business of educating undergraduates and providing continuing education programs. Within the last six months I have begun to receive 5 to 10 mailings a week from private firms that want to train me and my staff.

Perhaps the most appealing thing about these ads is that they provide very specific information about what I can expect to learn if I invest my time and money with a given firm. For example, one such flier may say, "Madame Professor, you are being asked by your administration and your accrediting organization to assess student outcomes. We'll show you how to do this in our deluxe executive seminar."

"What *is* student outcomes assessment?" the flier continues. "We define it as the process of collecting credible evidence of student learning for the purpose of improving academic programs and student services."

"When you complete our seminar, you will be able to *do* the following:

- State your course and curricular goals and objectives in terms of what STUDENTS WILL LEARN.
- Identify experiences that will enable students to achieve your learning objectives.
- Select or develop measures of student achievement of the objectives.
- Use these measures to gather data about student learning.
- Analyze and interpret the data.

- Use the findings to improve your courses, curriculum, and related student services."

"You will leave the seminar with a concrete plan that you can begin to implement immediately. And of course you will develop a network of colleagues on whom you may call for assistance. And all of this will occur in a relaxed off-campus setting, far from distracting phone calls and appointments."

Contrast this specificity with the language of *our* advertising materials — the college catalog or departmental bulletin: "As a first-year student you will take two semesters of Freshman Composition and two math courses, two natural science courses with labs, and two courses in social sciences selected from the following lists. In your major you are required to take one, three, two, and three courses, respectively, chosen from the following lists; and in your last semester you will complete a project in a senior design course. Graduates of this curriculum obtain good jobs in business, industry, and government, and many pursue graduate work at the nation's most prestigious institutions."

The prospective student is left to wonder, "*Why* must I take all those courses? What will I learn? What will it all add up to? What percentage of the graduates get "good" jobs? And what *is* a "good" job, anyway? What percentage of the graduating class goes to graduate school? What is a "prestigious" institution?" Most college departments would find it very difficult to answer the student's questions simply and directly, though most of us would admit they are logical and reasonable ones to ask.

What is our *evidence* that we are providing value for the dollars being invested in higher education? I believe that we should not be satisfied until it is as strong and convincing as the evidence we require when we judge the success of an experiment, the quality of a design, or the credibility of another scholar's arguments.

Over the last decade I've conferred with faculty about assessment on campuses in more than 30 states. During that time I've been discouraged to find that more than 90 percent of the course syllabi I've reviewed are written in terms of what faculty will teach — lecture topics and reading assignments — rather than what students will learn. And rare indeed is the program that states student learning outcomes for an entire curriculum.

Thus I was pleasantly surprised when I read the Collins/Ackermann paper (1996) and found that about 40 percent of the goals for undergraduate education that they obtained in their survey of civil engineering departments are stated in terms of what students will learn. Later in the paper I discovered that nearly all those learning outcomes were taken directly from the ABET criteria for accreditation, and suddenly I detected the faint odor of feet being held to a fire! But that's all right. If you are beginning to put student learning at the heart of your work, you are miles ahead of many of your colleagues in the academy. But I think you will recognize some of your colleagues in what follows.

Faculty resistance to, and lack of involvement in, assessment has been identified in two recent national surveys (Steele 1996; Ewell 1996) as the most significant barrier to the implementation of assessment. We can all identify reasons for this resistance.

When first presented with the possibility of developing an approach to the assessment of student outcomes, most faculty respond, "We assess all the time. We use course and cumulative grade point averages to tell us how students are doing. What's wrong with that?" We might respond that the average correlation between cumulative GPA and an array of measures of success in later life is 0.1 — nearly non-existent. But a more positive response is "Yes, you do a lot of assessment of individual student achievement, and that is the most immediate way to help students. But with our new emphasis on outcomes assessment, we need to look carefully at the achievement of groups of students to see what that may tell us about how to enrich our teaching, enable students to learn more, and improve the curriculum." The faculty response is often, "Why would we want to change the curriculum? Things are working well now."

Most faculty, especially those who have studied TQM, eventually admit that nothing is so perfect that it cannot be improved at least a little. In fact, if they are in public institutions, they may have been asked by a friend in the corporate sector, "How can you expect to stay in business with a scrap rate of 50% or more?" So they ask the next questions, "Where will I find the time to take on this new approach to assessment? And where will my department get the money it will take to do this new work?"

Faculty also express concern that collective agreement with colleagues on objectives for a curriculum will have the negative consequence of abridging an individual faculty member's academic freedom as he or she has to devote some teaching efforts toward promoting students' learning of the common curriculum objectives. The Collins/Ackermann study contains a simple statement that speaks volumes in this connection: A few departments in their survey said that "differences in values within a department prevented them from yet forming mission and goals statements that meet with faculty consensus."

Being asked to take time to learn new methods designed to improve pedagogy is often resented. Most faculty are not trained as teachers and many believe that good teachers are born, not made. Thus teaching is considered a private matter that is not often discussed extensively with colleagues. Faculty tend to shun teacher training and feel there is no need for them to engage in it.

So what about assessment in civil and environmental engineering? What are some ways that it can be done? First, don't think of assessment as simply giving a standardized test. In some ways engineers are fortunate in that you have sufficient faculty agreement about outcomes in your field to have the national Fundamentals of Engineering exam for undergraduates. Knowing your students' areas of strength and weakness over several years on that exam can help you assess your curriculum. But each of your departments has some objectives of its own that are not covered by the national exam, and no single assessment instrument should be used *alone* as evidence that a curriculum has successfully promoted student learning.

Later in this Section, Barbara Olds describes the wonderfully rich and comprehensive assessment method provided by portfolios. Here are a few other examples, based on some of the outcomes identified in the ABET criteria. Table 19-1 contains fifteen assessment methods that can be woven naturally into an engineering program, thus ensuring that students and faculty will regard them seriously. All of these methods can be used to assess more than one of the student learning

Table 19-1
Assessment Methods in Engineering

Assessment Method	Professional Practice	Engineering Design	Communication Skills	Teamwork Competence	Computer Literacy
Standardized Exams	–	–			–
Double-graded classroom tests	–	–	–		–
Faculty observation	–	–	–	–	–
Videotape analysis	–	–	–	–	–
Oral presentations	–	–	–	–	
Student questionnaires	–	–	–	–	–
Evaluations of internship	–	–	–	–	–
Senior design project	–	–	–	–	–
Focus groups	–	–	–	–	–
Student journals	–	–	–	–	–
Survey of alumni	–	–	–	–	–
Survey of employers	–	–	–	–	–
Problem-based learning evaluations	–	–	–	–	–
Exit interviews	–	–	–	–	–
Panels of practitioners	–	–	–	–	–

outcomes specified in the ABET criteria. For additional examples of faculty practice in assessment, please see the new book, *Assessment in Practice: Putting Principles to Work on College Campuses*, (Banta et al. 1996), which is based on 165 cases collected from colleges and universities across the country.

Faculty all over the country are developing simple scoring rubrics that enable them to reliably assess skills as disparate as mathematical competence, group interaction, and even critical thinking. In a capstone course, one might conduct assessment of virtually all fundamental engineering skills and competences by employing a variety of assignments — written, oral and in groups. Similarly, at the graduate level, faculty can agree on the kinds of knowledge and skills they would like to see students develop, then apply multi-level criteria on rating forms to projects, exams, oral presentations, research proposals, comprehensive written and oral exams, and theses or dissertations.

The times are changing — more rapidly than ever before. If there ever was a time when faculty could legitimately say "I can ignore assessment. It will go away," that time has certainly passed now. If one has any doubt that entities like higher education, which exist to provide services to others, can escape the obligation to demonstrate their accountability, one has only to look at the enormous changes in health care that are occurring at lightning speed and at the outcome-based agenda of every publicly-supported social service agency. Every new program we propose these days must have an assessment or evaluation component. Increasingly, federal and state agencies, and accrediting agencies such as ABET and our regional accreditors like the North Central, Southern, and Middle States Associations of Colleges and Schools, are asking us to provide concrete evidence of the effectiveness of our current programs.

Taxpayers and their representatives are looking for ways to educate the populace at the lowest possible cost. The governors of eleven Western states are discussing the establishment of a virtual university that would award credit by assessing students' abilities to demonstrate competence in college subjects. Coupled with interactive tele-learning that can make one well-constructed course available to students anywhere in the world, the virtual university concept has the potential to change fundamentally the way students experience postsecondary education.

All of these developments taken together suggest that faculty must be more intentional about what they will teach and what students will learn. There must be explicit, agreed-upon objectives for curricula and for the courses that comprise them. Above all, there must be assessment of student competence — demonstrable evidence that students are mastering the course and curricular objectives.

But you know what most faculty say about all this: "We know student competence when we see it. Most faculty in our department agree on the characteristics of the competent professional. Don't force us to narrow our vision by defining competence — by writing down what we think students should know and be able to do."

I agree wholeheartedly that what we teach should not be confined simply to what we can assess. Our abilities to assess complex learning effectively are primitive indeed.

But the fact of the matter is that if we don't set down the fundamental components that we will add to our students' knowledge and skills, others will. Many states — where block grants are focusing the action for the foreseeable future — are already asking *employers* to define competence, then contracting with private firms to deliver the needed skills — leaving colleges and universities out altogether.

Given the ferocious competition developing among learning organizations world-wide, setting standards for student learning and assessing student success in attaining these standards are simply necessary, but not sufficient, steps that faculty must take to preserve their own jobs and perhaps even the very existence of their institutions.

I recommend a new paper by Eugene Rice, director of the AAHE Forum on Faculty Roles and Rewards, entitled "Making a Place for the New American Scholar" (1996). In addition to calling for important changes in the graduate training we provide for prospective faculty, Rice offers a series of suggestions for "rethinking faculty careers." These include creating a departmental culture in which (1) collaboration is valued, assessed, and rewarded, and where faculty can easily cross disciplinary lines to collaborate with colleagues in other fields; (2) excellence in teaching, instructional scholarship, and public service are valued and rewarded as research is today and faculty have the opportunity to concentrate on each of these areas at different points in their careers; and (3) faculty have opportunities to spend extended periods of time learning from practice in settings outside the academy — making professional contributions of a different kind — then moving back into their academic appointments. Rice also suggests that tenure be considered local, tied to institutional mission. Thus, if assessing student outcomes and institutional effectiveness are valued sufficiently to be incorporated in an institutions's mission, its tenure-track faculty will have a powerful incentive indeed for becoming involved in assessment.

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Review of Mission and Goals of Civil Engineering Departments: Prerequisite for Outcomes Assessment

Anthony G. Collins

Engineering education is at a watershed in terms of switching from a "teaching" driven process to a "learning" environment whereby educational objectives are established and the success of achieving the objectives is to be measured via outcomes assessment. To achieve this transformation the Accreditation Board for Engineering and Technology (ABET) has established new accreditation criteria (ABET 2000, Peterson 1995). Rather than specifying a very constrained curricula that needs to be taught in each of the engineering disciplines, including environmental engineering, the new criteria is much less prescriptive and requires primarily an assessment of what has been learned by the engineering students as they exit the various disciplines.

The prerequisite first step of this new approach to engineering education is the formulation and publication of mission and goal statements for each engineering discipline (usually an engineering department). Once goals are clearly established, then strategies to achieve the goals can be formulated and implemented. The final step in the process is assessment of goal achievement.

This paper reports on the current national status of mission and goal statements of civil engineering department through a comprehensive review of existing documents. Survey requests were mailed to 224 college and university civil engineering departments. Material from 67 departments was eventually analyzed in the study from the over 70 responses received. Data from this survey (Collins and Ackermann 1996) is of interest to the environmental engineering education community as the majority of departments surveyed contained environmental engineering programs.

As the complete survey is available from the 1996 ASEE Annual Conference Proceedings, it is appropriate to only restate some of the major observations. In studying the mission and goal statements of the 67 civil engineering programs, it was apparent that there has been a lack of uniformity in the approach used to define the mission and goal statements. The broad, more global goals for departments were often the outcome of strategic planning exercises, usually initiated at the university-wide level and then filtered down to departments. In some cases, strengths were identified and means by which these strengths could be maintained were stated. In other cases, departmental statements only highlighted deficiencies and remedial steps by which they could be corrected. If these broader, global goals were identified, frequently they were limited to three or four goals so that within the framework of a strategic planning exercise they would be "achievable".

The undergraduate educational goals of the departments were more specific. Quality undergraduate education was a universal goal. There was a strong connection between graduate education and the coupled elements of research and scholarship. The objectives of ABET influenced the choice of goals as a subset consisting of about 15% of programs have similar, ABET-oriented goals. Specific undergraduate goals did not reflect student-faculty intensive activities, interdisciplinary activities or student development.

In reviewing the mission and goal statements, it was obvious that there is great value in identifying program strengths and weaknesses and in undertaking the strategic planning process itself. Those programs that are traditionally considered as strong programs had the most comprehensive documentation. Clearly there is value to be gained in simply undertaking the activity. It is hoped that the survey results may be a point of departure for such exercises.

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A Portfolio Approach to Outcomes Assessment

Barbara M. Olds

Introduction

Assessment is clearly on the minds of engineering educators these days, especially as the conversation surrounding the ABET 2000 criteria (1996) heats up. At the Colorado School of Mines (CSM), we are perhaps at an advantage because we have been using portfolios to assess the engineering education our students receive — both in the core and in their majors — for nearly 10 years. In this paper I will briefly describe the history of our assessment program and its current process, discuss why we chose the portfolio approach, provide examples of the materials we collect to address various goals, give examples of curricular changes resulting from our assessments, discuss some of the strengths and weaknesses of portfolio assessment, and look to the future of our assessment efforts at CSM.

A Brief History of Assessment in Colorado and at CSM

In the late 1980s, Colorado, like many other states, became interested in higher education accountability and assessment and passed legislation (HB1187) requiring the Colorado Commission on Higher Education (CCHE) to "develop an accountability policy and report annually on its implementation." In addition, the legislation required that institutions of higher learning be held accountable for improvements in student knowledge between entrance and graduation; that these improvements be publicly announced and available; that institutions express clearly to students their expectations of student performance; and that these improvements be achieved through effective use of time, effort, and money. The state required each institution to report assessment of general education, discipline-specific education, retention and completion, alumni/student satisfaction, after-graduation performance, minority student statistics, and costs. According to the timeline established by CCHE, each institution was required to submit its institutional goals and objectives for approval in 1988 and then submit an assessment plan after the goals were approved. In 1989 the first assessment reports were submitted. The legislation stipulated that CCHE could retain two percent of an institution's appropriation if it found the assessment report "unsatisfactory."

Unlike several states in which institutions with very dissimilar student bodies, goals, and missions were required to use identical measures, Colorado allowed each institution to develop an individual assessment plan appropriate for its size, student body, mission, and goals. After considerable input from alumni, recruiters, faculty, and students, CSM chose to develop a *portfolio assessment program* which we have been using since 1989. The school has had both North Central and ABET accreditation visits since then, with positive feedback on our assessment program from both. Inronically, just at a time when accrediting groups such as ABET are becoming very interested in assessment of student outcomes, the Colorado legislature recently passed House Bill 1219 which repealed the higher education assessment program and replaced it with the "Higher Education Quality Assurance Act" based on performance indicators to be established by the Colorado Commision on Higher Education and the governing boards of state institutions. Although Colorado is changing its accountability focus to performance standards, CSM intends to continue our assessment program, with appropriate modifications, because we believe it provides us with valuable information about teaching and learning at our institution. We agree with Courts and McInerney's conclusion (1993) that "the only valid reason for doing assessment of any kind is to improve the teaching/learning enterprise."

The Portfolio Assessment Program Process

As a major part of its CCHE-approved assessment plan, CSM proposed using a portfolio system based on maintaining comprehensive longitudinal records for a statistically-based sample of CSM students (Olds and Pavelich 1996). The plan was developed with input from students, faculty, administrators, alumni, and employers. In brief, each year a random sample of incoming students is selected (approximately 10 percent of the freshman class) for whom we develop portfolios. For these students we collect typical quantitative data such as SAT and ACT scores and GPAs; in addition, we include in the portfolios samples of classroom work from a variety of courses as well as surveys and other feedback on the student's satisfaction with the institution. Each spring the portfolios are evaluated by a faculty Assessment Committee whose summary provides the heart of our annual report to the campus and CCHE.

At the beginning of each semester, the registrar provides the assessment coordinator with class lists for all portfolio students. Based on these lists, professors and department heads are contacted twice during the semester and reminded to collect pertinent materials. The materials collected for freshman and sophomore students are forwarded to the Assessment Committee and are filed in each student's portfolio for evaluation later in the year. Each major department retains the materials on its juniors and seniors to be evaluated by a departmental assessment committee. We made a conscious decision to place as little burden as possible on the individual student in this process since our goal was institutional and programmatic assessment, not assessment of individual progress. In our plan, students involved in the assessment process are only vaguely aware that their coursework is being collected and evaluated, even though they and/or their parents sign a consent form when they are selected for the program. However, we believe that strong arguments can be made for involving students more in the assessment process by having them collect (perhaps even select) the material for the portfolios and particularly by having them write periodic self-reflection/assessment papers to include in the portfolio. As we revise our assessment plan in light of changes at ABET and in Colorado, there is some sentiment for moving in this direction. Such portfolios, if students are convinced of their worth, would provide opportunities for student learning (especially if they are reviewed frequently with an advisor) and could also be a powerful demonstration to potential employers of what a student knows and can do.

The Assessment Committee, with approximately 10 members from disciplines across campus, meets regularly during the academic year to discuss assessment issues and then for two days after the end of the school year to evaluate freshman and sophomore portfolios. The current committee includes representatives from engineering, mathematics, chemistry, physics, geology, and liberal arts. Their evaluations and recommendations (always in the aggregate), along with those from the separate departmental committees who assess the majors, form the basis of the annual report to the CSM campus and to CCHE. (Olds 1995)

Although their helpful guidelines were published long after our assessment plan was developed and implemented, we believe that CSM followed most of the recommendations provided by Rogers and Sandos in "Stepping Ahead: An Assessment Plan Development Guide" (1996). Specifically, Rogers and Sandos define an eight-step process which can be used to develop an assessment plan:

1. Identify goals
2. Identify objectives
3. Develop performance criterion(a)
4. Determine practice(s)
5. Specify assessment methods
6. Conduct assessments
7. Determine feedback channels
8. Evaluate

Based on our institutional mission and goals as defined in our Profile of the CSM Graduate, we decided to assess the following areas: technical ability and knowledge; communication skills (oral, written, graphic, computing); critical thinking and intellectual development; ability to self-educate; familiarity with the humanities and social sciences; and teamwork and leadership. Our current curriculum revision process has modified these goals somewhat (emphasizing international perspectives more, for example) and our assessment process will need to be modified as a result.

However, these attributes mesh remarkably well with those delineated in the ABET 2000 Criterion 2 which requires that each engineering program have in place "detailed published educational objectives that are consistent with the mission of the institution."

In developing our plan, we did not focus on Rogers and Sandos' next several steps individually, but we believe that all were addressed in our process. Rogers and Sandos (1996) argue that the second step should be identifying objective(s) for each goal, declaring that "objectives are precise in stating expected change, how the change should be manifested, the expected level of change, and over what time period the change is expected. Objectives should guide *practices*." Their third step calls for performance criteria which are either the level of performance required to meet the objective or an indicator (e.g., a survey) of it. The fourth step involves defining classroom and/or institutional practices designed to achieve a specific performance, and the fifth step is specifying the assessment methods to be used for each objective. We approached these steps by developing a matrix of places in the curriculum where each of our goals should be emphasized and a list of course materials to collect which should reflect them. The matrix is reproduced in Table 21-1. This matrix is used by the Assessment Committee and the departments to identify which specific materials should be collected and evaluated each year.

Rogers and Sandos' sixth step (1996) is to conduct assessments by developing "surveys, rating sheets, interview and focus group protocols, etc. as approriate." Our committee established the guidelines for evaluating the collected student work. This occupied a great deal of the Assessment Committee's time and talent in the first several years of the program. What they developed has worked well: the guidelines are straightforward, analytical, and give reproducible results among a variety of faculty evaluators. For example, the instruments we developed for evaluating critical thinking and technical abilities are given in Tables 21-2 and 21-3. The evaluator is asked to judge the student's ability in universal categories such as the ability to use

Table 21-1
The CSM Assessment Portfolio (Revised 1990)

OBJECTIVE MEASURE	ENTRY	FRESHMAN	SOPHOMORE	JUNIOR	SENIOR	POST GRAD
Technical Ability/ Knowledge	ACT/SAT Scores	EP 102 Computer Aps EP 101 Final Report CH 124 Final Exam PH 132 Final Exam GE 101 Final Exam Math Final Exam (highest class)	EP 202 Area Report Math Final Exam (highest class) PH 231 Final	MATERIAL SELECTED BY OPTION DEPT. Option Final Exam(s) Sample Computer Program	GRE or EIT if approp Senior Design Final Report	Placement Info. Alumni Survey Employer Survey
Communication Skills		HU 100 Paper EP 101 Final Report EP 102 Oral Report Video	EP 202 Area Report EP 202 Oral Report Video	Summer Field Session Report	Senior Design Report Senior Design Oral Video Senior Seminar Essay	Alumni Survey Employer Survey
Critical Thinking/ Intellectual Development	Perry Data Self-assessment	HU 101 Paper EP 101 Final Report			Perry Data Self-assessment Evaluation by Option Dept.	
Cultural Knowledge Ethics International Awareness		HU 100 Paper Defining Issues Test			Senior Seminar Essay	Alumni Survey Employer Survey
Life-Long Learning Ability					Exit Survey/ Interview	Alumni Survey Employer Survey

Table 21-2
Critical Thinking Form

Student Name ____________________ Entry Year _________

Materials Evaluated ____________________ Date ___/___/___

Ranking Scale:	5 = strongly done
	4 = well done
	3 = satisfactorily done
	2 = poorly done
	1 = not done

I ___________ Problem statement
(problem clearly stated; solution addresses problem: technical, economic, social aspects addressed)

II ___________ Evidence
(evidence used; all evidence pertinent; logic is clear, convincing)

III ___________ Judgment
(alternatives shown; consequences stated; qualifications stated; risks vs. benefits examined)

IV ___________ Creativity

Table 21-3
Technical Evaluation Form

Student Name ____________________ Entry Year _________

Materials Evaluated ____________________ Date ___/___/___

Ranking Scale:	5 = very high competence
	4 = high competence
	3 = adequate competence
	2 = weak competence
	1 = no competence shown

I. Knowledge

_____ terminology

_____ elementary principles

_____ advanced principles

II. Problem-solving

_____ single concept applications

_____ multiple concept applications

evidence in critical thinking and the ability to solve multi-step problems in technical competence. The process of defining these criteria and arguing about their meaning was a very valuable part of the assessment process. For this reason we agree with Courts and McInerney (1993) that the kind of qualitative assessment involved in a portfolio system "demands that those doing the assessing create their own instruments, criteria, and scoring system. The first step in assessment is to be sure that you are assessing your program and not someone else's or some fictional program that you have created in your own minds."

Rogers and Sandos' final two categories involve determining feedback channels and evaluating whether or not the performance criteria were met and the objectives were achieved. These steps will be discussed in more detail below, but in general the feedback to external stakeholders (the CCHE, the Colorado legislature) was appropriate and successful while the truly important feedback, the internal type which drives learning and teaching, was less so.

The Case for Portfolios

After nearly a decade of portfolio assessment, we have concluded that this method of assessment has some definite advantages. First, many educators agree that there has been serious dissatisfaction with overdependency on standardized testing. Though we see legitimate uses for standardized tests such as the Graduate Record Examination or the Fundamentals of Engineering exam, we also see the potential for problems of the type articulated by Courts and McInerney (1993):

> All too often, it seems to us, those who create the tests are far (entirely?) removed from the specific programs, curricula, and students to be tested. This lack of connection results in "generic" tests — tests that simply (or complexly) engage in assessing something, but what exactly the nature of that "something" is often remains clouded in jargon: that is, while the tests may "clearly" state that they are assessing a given program, ability, or skill, the specific elements within the program to be assessed are often fuzzily articulated; or, while

a given skill (reading, writing) may be identified, the complex nature of the skill is often poorly delineated and unrelated to the genuine nature of the ability or skill to be tested.

In addition, it has been argued (Forrest 1990) that evaluation activities should draw upon and support teaching activities, not intrude on or even detract from them. We believe that portfolios address this concern. We collect material that is already being used in the teaching/learning process and that therefore already has meaning to both students and faculty. Many of these materials can be used in a variety of ways. For example, a single paper from a freshman humanities and social sciences class may tell us something about a student's writing ability, critical thinking skills, and ethical stance.

Second, there is evidence that tracking students over time gives the best information about how to improve student learning. For example, the Joint Task Force on Engineering Education Assessment (1996) argues that "As program improvement is the objective of assessment, schools are cautioned to assure that assessment results are measuring the consequences of a program characteristic that has operated for a sufficiently long period of time to provide a causal relationship to the outcomes being measured." Since the goal of our process is to provide our colleagues with both formative and summative information about the teaching/learning process, portfolios provide a particularly rich means of accomplishing this goal. We discuss below some of the changes that have taken place in our curriculum as a result of the assessment process. In addition, we have been able to use data from our sample to study such issues as graduation rates, number and sequence of humanities and social sciences courses taken, and comparisons between the published "normal" core sequence for students and what they actually take. Our ability to evaluate the success of our programs will, we believe, increase as we are able to follow the careers of the assessment students who have graduated.

Finally, most assessment experts agree that no single instrument is adequate and that we need to use several assessment techniques simultaneously or to "triangulate." The Joint Task Force (1996) says that "Clearly, no one assessment device will suffice for all the educational objectives that we expect the modern engineering graduate to obtain from today's university education." We believe that portfolios allow us to collect a variety of materials in a non-intrusive way. We agree with Forrest that there are additional advantages to portfolio assessment: it builds on existing assessment activities and is not radical; it can be implemented piece by piece (even in a single course); it can be adapted to the local culture and to the local motivations for assessment; it can be cost effective; and it can be explored by involving only a small number of students, faculty, and administrators initially.

Examples of Portfolio Materials

A critical task of the portfolio approach is to identify coursework in each year that reflects the students' abilities in one of our goals areas. Table 21-1 lists the materials collected from students in the sample and the curricular goal into which they give some insight. For example, we collect team-produced final reports from our introductory design course (EP 101) and analyze them for evidence of communication skills and critical thinking abilities. We also evaluate individual written reports from students' humanities courses for the same skills and abilities. In addition, we collect and evaluate videotaped oral presentations from the freshman, sophomore, and senior years. Students' final exams in their technical courses, senior design project final reports, and GRE or FE scores are among the tools selected by departments to assess students' technical abilities.

The Perry test listed in the two tables refers to hour-long interviews conducted with a smaller sample of students that give a direct measure of students' ability to understand and deal with the complexities and vagaries of open-ended problems. It uses William Perry's Model of Intellectual Development and thus is one direct measure of critical thinking abilities. Our data on this measure are available in the literature. (Pavelich and Moore 1993; Pavelich, Olds, and Miller 1995)

Each year the Assessment Committee examines each portfolio and judges each student's competence in meeting our learning objectives (see the five-point scales in Tables 21-2 and 21-3) compared to our experienced judgment of what a graduating senior should know and be able to do. Comparisons of several Assessment Committee members' evaluations show reasonable consistency and we work each year to norm our holistic scoring rubrics before beginning the assessment process. Such methods have been shown to be remarkably reliable.

Changes Linked to the Assessment Process

Since the assessment program was begun to meet a legislative mandate, we focused on satisfying legislative audiences for the first several years. We were able to document gratifying progress in student learning in most categories and our portfolio approach was praised by the CCHE. However, we have since begun to focus more on using our assessment data to provide feedback to departments and individual faculty so that they can fine tune their programs and courses. For example, one department collected its students' writing samples in the junior and senior years and noticed that they were requiring only perfunctory writing. The professors involved changed their requirements to provide more in-depth opportunities for student writing with the result that their students have become more proficient writers. Another department noticed that the introductory course exams did not include any questions that could be used to evaluate students' higher level technical thinking; they required only direct recall. The faculty in that department have made a concerted effort to include more multi-step, "synthesis" questions into their course content and on their exams.

There have also been some institutional changes as a result of assessment. The faculty evaluating freshman and sophomore writing have noticed spottiness in the quality of recent student work and inconsistency in the standards of faculty grading. We attribute these problems to our writing program having lost its leadership and have committed the School to hiring one or two communications experts to redesign and oversee our writing-across-the-curriculum efforts.

Another example of change goes back to the Perry data we have collected which indicate that CSM students show somewhat greater improvement in higher-level thinking ability than is normally found in undergraduate students. We attribute much of this to their extensive experience with real-world design problems from their freshman year on. However, we would like to see even more students reaching higher levels. A group of faculty working with freshman design has taken on the task of analyzing how we can better mentor students in design courses to facilitate their intellectual development.

Strengths and Weaknesses

There are several strengths to the portfolio method: it does not intrude on normal classroom procedures; it allows us to view multiple examples of a student's work over time; it is deeply analytical; feedback can be used for both formative and summative course changes. In addition, we have seen a heightened awareness of assessment and the need for continuous improvement on our campus, some real change in courses and programs, faculty involvement in the process through our bottom-up approach, and a data-based decision-making process.

The only major weakness we have seen lies in our underuse of the rich data we have collected. Specifically, we have not yet devised a way to make full use of the data as a continuous improvement feedback mechanism for our courses and programs. Part of the reason is historical; since the assessment program grew out of a political mandate, most of our early effort was focused on meeting the needs of outside constituents. This led to lack of buy-in from several departments and lack of knowledge about the assessment processes among some campus groups. We are addressing this failing in our current process and have focussed our recent efforts much more on the campus community and how assessment can benefit it.

The Next Step

We see a wonderful opportunity to strengthen our use of assessment as direct feedback, as an integral and natural part of our course and program design. CSM is in the midst of an undergraduate curriculum redesign effort. As a faculty we have rethought and rearticulated our goals, we have developed a curricular framework that contains some exciting innovations, and we have large numbers of faculty from all departments working energetically to redesign specific pieces of the curriculum. As part of the redesign process each of these working groups has been asked to supply an assessment component with their course or program plan. Thus we hope to see assessment built in as an integral part of our new curriculum by faculty who design assessment measures to meet their specific needs. The Assessment Committee is focusing its efforts on advising these faculty groups as they develop appropriate assessment strategies. We recently spent three days discussing the new ABET criteria and where the various attributes could be developed in our proposed curricula. Then we brainstormed various assessment techniques that could be used to measure each. For example, among the menu of options we developed for measuring Criterion 3, attribute (a), "an ability to apply knowledge of mathematics, science, and engineering," were: a senior comprehensive exam; application questions in exams (faculty identify the concepts being assessed); oral exams; the FE exam; field session reports; suitably identified homework; papers; modeling; word problems that test "translation" skills; and methods of checking "carryover" knowledge from one discipline to another. These options, and a variety of others, will be discussed with the various programs on campus as we work with faculty to design authentic assessments of student learning. We believe that our experience over the past decade has provided us with insights and experiences that will make the new CSM assessment process even more effective.

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The Role of Outcomes Assessment in ABET's Criteria 2000 for Engineering Accreditation

Joseph Sussman

We view, at ABET, or more particularly at the Engineering Accreditation Commission which I represent, Criteria 2000 as an attempt to make things better. But I want to be very clear. There is no monolith sitting in Washington or in Baltimore populated by techno bureaucrats called ABET foisting these requirements onto programs around the country. You are ABET. I am ABET. Your professional and technical societies are represented at the Engineering Accreditation Commission, entirely consistent with the population of your membership. You have two members on the Engineering Accreditation Commission representing environmental engineering and insofar as you have a problem with Criteria 2000 or with your program criteria as they ultimately evolve, blame me, blame them. There is no ABET, but rather, there is this consortium of professional and technical interests.

We view this outcomes assessment enterprise as the industrial equivalent of continuous quality improvement. If we're going to have a process, and we need to consider the fundamental basis, consider the attributes of the graduates rather than simply what they were taught. It's easy to go onto a campus and assess what people are being taught. You just go and take out various measurement sticks and measure. It's not so easy to measure what people have learned. And, so, therefore, everything that's gone on in your conversations about outcomes assessment is toward the issue of exactly how do we do it and what planning is required?

There are many schools that have had success with outcomes assessment. If you interview them privately, they'll all tell you that there are shortcomings with the process.

I joke, in my industrial career, with the young engineers and scientists that work with and for me about the fact that *change* is inevitable. *Growth* is optional. We are changing this process at your behest, at industry's behest, and we will do that. Whether we all grow from the process is, I guess, up to all of us.

The elements of the ABET criteria, Criteria 2000 are listed in Figure 22-1. Criterion One talks about accrediting programs, and it says, "The institution must evaluate, advise, and monitor students..." The "*must*", in the criterion is very rare, since ABET doesn't like to use must, it likes to use *should*. So here, you've got a must, you've got a measurement demand, and you've got reference to objectives. It's not ABET's role to tell you how to develop objectives, but rather to force the issue that you have some.

Criterion Two talks to that issue very specifically. "Each program for which you seek accreditation must have in place detailed, published objectives." I can't know, unless you teach me how to know, that these are consistent with the mission of the institution. There is no formula that ABET will apply. So when a team comes to campus, it will ask you to demonstrate that the program educational objectives are consistent with the institution. And you could imagine an institution developing a middle-of-the-road philosophy. We want to take average high school graduates and turn them into average engineers. And this is the way the "rhubarb engineering" program does that, and then demonstrate a set of objectives that are consistent with being average. I don't recommend that to you, but if it was consistent, it would be okay.

You need a process. You need to tell me, or any program evaluator, but more important you need to tell yourselves how these objectives are determined. How do you evaluate whether these objectives are the right objectives? Does the curriculum and the process that you use (and this is where continuous quality improvement philosophy comes in) help to ensure the achievement of the objectives that

Figure 22-1
Engineering Criteria 2000

Criterion One — Students

An important consideration in the evaluation of an engineering program is the quality and performance of the students and graduates. The institution must evaluate, advise, and monitor students to determine its success in meeting program objectives.

Criterion Two — Program Educational Objectives

Each engineering program for which an institution seeks accreditation or reaccreditation must have in place:

- detailed published educational objectives that are consistent with the mission of the institution and these criteria
- a process based on the needs of the programs' various constituencies in which the objectives are determined and periodically evaluated
- a curriculum and process that ensures the achievement of these objectives
- a system of ongoing evaluation that demonstrates achievement of these objectives and uses the results to improve the effectiveness of the program

Criterion Three — Program Outcomes and Assessment

Each program must have an assessment process with documented results. Evidence must be given that the results are applied to the further development and improvement of the program. The assessment process must demonstrate that the outcomes important to the mission of the institution and the objectives of the program are being measured.

Evidence that may be used includes, but is not limited to:

- student portfolios, including design projects
- nationally-normed subject content examinations
- alumni surveys that document professional accomplishments and career development activities
- employer surveys
- placement data of graduates

Engineering programs must demonstrate that their graduates have:

- an ability to communicate effectively
- the broad education necessary to understand the impact of engineering solutions in a global/societal context
- a recognition of the need for and an ability to engage in life-long learning
- a knowledge of contemporary issues
- an ability to use the techniques, skills, and modem engineering tolls necessary for engineering practice
- an ability to apply knowledge of mathematics, science, and engineering
- an ability to design and conduct experiments, as well as to analyze and interpret data
- an ability to design a system, component, or process to meet desired needs
- an ability to function on multi-disciplinary teams
- an ability to identify, formulate, and solve engineering problems
- an understanding of professional and ethical responsibility

you, yourself, set? And what's the system that you use? This is the heart of the struggle. How do you take the results that you measure, whatever those results may be, and feed them back into the system?

This has got to become a closed loop system and it certainly won't become that overnight. ABET, the Engineering Accreditation Commission, is mindful of that. We started with some pilot visits in the fall of 1996, and two pilots will be conducted. I'm not telling you anything secret, although it may not be well publicized. Two pilots will be conducted, one to a small, private school, and one to a large state school, one of which claims it has been doing outcomes assessment for the last twenty years, and one which has just prepared itself to start doing it consistent with the likely passage of Criteria 2000. So, one group of people is going to Worchester Polytechnic Institute in Worchester, Massachusetts, and one group of people is going to the University of Arkansas in Fayetteville. We hope to learn a great deal about how the institution presents its claim, and how the team assesses that claim or set of claims against the criteria.

But before going further, I want to mention the most important part of Criterion Three. Criterion Three, which says, "Engineering programs must demonstrate that their graduates have..." We all have that. You can get that list from headquarters. The most important part of Criterion Three is the part that comes before the list. The words are "Assessment process, documented results." What I emphasize is "Results are applied to the further development improvement of the program. The assessment process must demonstrate that the outcomes important to the mission of the institution and the objectives of the program are being measured." ABET does not have a quick, simple means by which to teach how to measure that which you need to know. But, rather, is looking for you to explain how you do it, why it is the right set of measurements, and how you use them to make the program better.

These criteria are one year old, and I worked on their development, with a lot of debate, a lot of discussion with your representatives, representatives from all of the societies, worked hard, and then at the end of the day they were adopted unanimously. We are going to do this.

There are resources for those of you who haven't been involved in the creation of criteria (Figure 22-2). If you are accessing the World Wide Web, daily or weekly, you will find updated program criteria. In addition, you'll see some moderate changes to the general criteria as a result of the most recent EAC meeting in July. The Web Site is easy, it's just www.abet.ba.md.us. You will find Criteria 2000, and you'll find program criteria.

Figure 22-2
Resources

ABET Web Site: http://ww.abet.ba.md.us/

Vision for Change: A Summary Report of the ABET/NSF/Industry Workshops

Engineering Criteria 2000: ABET Publication AB-7a

Stepping Ahead: An Assessment Plan Development Guide by Gloria Rogers, Jean K. Sando for the Rose-Hulman Institute of Technology

I commend you on the high-minded statements of purpose that your program criteria represent. I caution you that they may not be adopted by the Commission exactly as you wrote them. But that will be a debate that goes on for the next nine or ten months.

We did convince the NSF that this was a complicated business and we needed help. So they funded a series of workshops on how to do this change. They are now funding case study materials for you as a result of the visit at Worchester and at Arkansas and at four other institutions as yet unnamed. Those four institutions will be done in the 1997-1998 accreditation term. And there will be a call for volunteer institutions if anybody feels that they're ready to step up to the challenge.

Let me describe these pilot visits. We're very concerned about the learnings that might unfold; we are not concerned that they'll be successful visits. They may be nightmares to conduct. I am conducting one. I am the team chair for one of those visits. We were so concerned that we staffed the teams with Commissioners. For these visits we're not reaching into the technical societies representing the programs that are on those two campuses to find program evaluators, but rather we're taking Commissioners from the EAC who represent those technical societies, and having them come along.

For example, I'm going to Worchester. There are six programs at Worchester, and I am taking six Commissioners, each of whom represents that technical area of the program under examination. We have spent a lot of time, effort and energy already with Worchester trying to discuss how they will demonstrate what it is that they're doing consistent with the criteria. This is a very difficult enterprise.

Finally, I want to say that it's nice to come to a strange place with people whom you've never met and hear them all talking about the same set of issues, using the same terms. It's almost like learning ballroom dancing in the East and then going out West and finding out that you can dance with all the ladies.

I heard everybody say this: It's not what students have been taught, but rather what they have learned. And how do you measure what students have learned? We acknowledge openly that this is difficult. We acknowledge that this is something that we have all agreed to do. It will not go away.

***About the Author** — Joseph L. Sussman is the Senior Vice President of Manufacturing at Bayer Diagnostics in Tarrytown, New York.*

SECTION 7

Summary

Conference Overview

Roger J. Dolan

It was a pleasure to participate in this conference. It has been an interesting experience to drop into a world of educators discussing matters of vital importance to the next generation of environmental engineers. This is a world which I left thirty years ago, but the knowledge and values imprinted on me at that time are a fundamental part of me to this day.

I would begin by commending the John Prados (National Science Foundation) presentation "Engineering Education for the 21st Century" as being a better comprehensive overview of where we are and ought to be heading than anything I could do in my brief time allowance. While this presentation had been prepared in advance, it nicely summarized what many of the preceding speakers had said. I would like to devote my comments to a few observations and opinions about the conference and our business.

Consensus — There was a substantial consensus on what's happening to our business. In a nutshell:

- The focus of energy has moved from compliance with regulations to becoming more competitive; for both dischargers and goods and service providers.
- Substantial organizational shifting is now occurring. This is producing new winners and losers.
- A substantial amount of our business has become global.
- Information age tools and resources are changing the way we do our work.
- Change is a way of life. An excellent knowledge base and a commitment to life-long learning are imperative to success.

The high degree of consensus on what is happening now provides some comfort as to the accuracy of the perception of the status quo. However, we can take no comfort from consensus on predications of where the business is going. Extrapolations of concurrent interrelated trends has been notoriously unreliable. In the field of economic forecasting this consensus among the experts has become recognized as a fairly reliable contra-indicator. The message here is that since we can't put much stock in predictions, flexibility, adaptability, and being light on your feed will probably be the best approach. One lesson of recent history is that institutions and individuals at the top of the heap will have to struggle to maintain their position, while smaller, more risk-taking, less hide-bound institutions and individuals will continue to make gains.

Now for some ideas about the concepts we discussed.

Fundamentals — Given the need for a rock solid education, the natural response of the educators is to maintain an emphasis on *fundamentals*. Here again we heard a consensus. Practitioners said we need engineers trained in fundamentals. Educators said we need to continue to teach fundamentals.

However, I would ask you if we can be sure everyone meant the same thing by the word fundamental. There is a chance that the practitioners meant fundamentals to include skills at oral and written communication, teamwork, and developing workable cross-cultural interpersonal relations; while the educators might have meant teaching a calculus based grand unifying theory of biological process. If that is so, then the educators will go home with the misimpression that they do not need to change. When this group reassembles in five years, I suggest that you collectively agree to eschew the word fundamentals and try to discipline everyone to use more specific terminology.

Outcomes Assessments - I applaud incorporation of outcomes assessments into the evaluation of educational programs. I also share with you a certain degree of reservation as to how to do it and what are the unintended consequences of the various options.

If I were asked how I would rank successful environmental engineers, it might go something like this:

- Grade A goes to engineers who leave a legacy of constructive change either through their physical works, intellectual contributions, institutional changes, or the positive influence they have on others who have made such contributions to humankind.
- Grade B goes to those productive contributors working away in the field for which you prepared them.
- Grade C (or maybe B±) would go to those who left the profession but succeeded elsewhere at least in part due to the momentum you gave them.
- Grace D would go to those disillusioned workers who feel caught in a game they can't win; grinding out the work with a sense of entrapment and a lack of fulfillment.
- Grade F goes to people who flunk out of the profession.

It seems really difficult to correlate that list with the operational functions of an institute of higher learning. So much depends on the personalities of the graduates as well as specific opportunities, ambitions, and each person's ability to make the most of setbacks.

Each year you shake a giant dice cup containing from 10 to 100 dice and spill it out on the bar top of life. Some of those dice will be rolling for 40 years. It would take 10 years to really get much of a trajectory on many of these people. Some engineers fit in well and start strong, yet many plateau early. Others may not be thought highly of by their employers after two to five years, yet 15 years later they may emerge as the leaders, partly because of their obstreperous ability to put up with the status quo.

I have a thought to share. It may be possible to think of the educational objectives along two important but parallel tracks; one oriented at producing an engineer who can produce usable work in time to cash her first paycheck. This track can be evaluated by percent passing the EIT or their employers' appraisal of their successful accomplishment of complex work assignments within three to five years, for example.

The second track is more long-term oriented and results from the impartation of values, ethics, and motivation from the direct person-to-person contact between teachers and students. This portion of the education process may be evaluated by such devices as interviews of focus groups of randomly selected graduates considering such topics as the role of their university in shaping their ethics, professionalism, motivation, intellectual curiosity, and career goals.

Track two will be more difficult to quantify reliably than track one. One of the unintended consequences of placing too much emphasis on track one skill evaluation is that it will naturally lead to a de-emphasis of track two training, and track two training is what will be shaping the Grade A graduates.

Communication Skills - I had to change my mind about the subject of teaching communications skills during this conference. Before the conference I would have told you not to worry so much about it. Most entry level engineers are poor writers and not much better speakers. Most ten-year veterans are pretty good — some, of course, better than others. My experience is that the best way to become a good writer is to write a lot. Most students just don't have enough experience at it, but will eventually.

However, I heard all the practitioners say they wanted graduates who were better trained at communication. The way I look at it is: they are the customers and the customers define quality. So, I'd say improvement is needed.

Based on my own personal experience, I would advise you not to simply do more of what you are doing now. I would expect a normal reaction to be to get out the red pencil and make more red marks on the student paper, and maybe grade them more critically on their writing performance than presume they will figure it out and get better. If they are anything like me, they won't. I was never very good at learning from returned papers. I pretty much put that work behind me and concentrated on the next assignment. Instead, I think writing needs to be taught specifically.

There are a few key messages that need to be understood by the students. First, they must reject the bias that engineers are inherently poor communicators and that communication is something that's best left to a non-technical person. The number one problem we are addressing is the communication of technical concepts to both technical and non-technical people. This is not a job for the non-techs. Writing skills are learned, not innate, and anyone can learn them. For technical writing the goal is to be understood and not to impress. Simply phraseology and short simple sentences get the job done better. Your success as an engineer will be greatly impacted by your ability as a communicator. And, lastly, the best way to become a good writer is to be a good reader. Most engineers are not good readers. Being a prolific reader is not only important for one's writing skill, it also is one of the best ways to keep current with our changing world. This is a value area where the personal influence of the professors could really pay off.

One additional thought about imposing additional courses like Communication into the curriculum — I feel that it would be better to teach Communication as a part of the technical training. We start with the understanding that there is already not enough time, and college administrators want to cut it more. Some course material is very difficult to grasp and takes a lot of effort, including a stiff homework load, for the students to understand it. These courses can only be taught by a limited number of experts, often using laboratories to round out the understanding. Please don't push this course work aside for training in the softer areas that can be learned by post-graduate training. Maybe the practitioners need to accept a training responsibility too. Life-long learning is better suited to updating well founded knowledge, or enhancing skills in communication and teamwork, than it is for developing the basic math, science, and technology of our field. It is difficult to learn the "hard" stuff when you are in your 30's, 40's, and 50's.

Teamwork — We heard a lot about teamwork. There is no getting away from it, virtually everything we do, we do in teams. Good team players are more successful. Teaching team skills is a great idea.

I really like to work on teams. I enjoy the fellowship, the energy and the synthesis. But, I hated school team projects. The reason is that I always found myself teamed up with some likable, lethargic, knuckle dragger who dragged the team down. We didn't have the tools to make them produce. One good way to really set back young engineers is to give them more of the same. I have an idea on how you can improve things. First, let the students get to know each other, then have them form their own teams. The professor should set up some rules that mimic a job situation. First, I suggest you establish a budget of time for the project. The team should elect a leader and divide the budget up based on assignments. The leader should be easily impeachable by majority vote. Don't worry if the budgeted number of hours is not too accurate; the students will have to spend the time it takes. Before the team passes in the assignment they should have a project management meeting and, by consensus, reappraise each person's time as a percentage of the budget. This information would be given to the professor who could use it in grading if she wishes.

Professionalism — Another subject that came up several times this week which was not on the agenda was the topic of professionalism. It is a subject that seems to surface whenever a critical mass of us get together. That fact alone gives credence to the thought that there is at least some insecurity among us as to whether we are viewed by the public as high ranking professionals.

The forces that deal with professionalism in engineering are larger than all of us in the room together; they are larger than the engineering business because they deal with societal values. While the degree of education is a consideration, years of education alone do not define a professional. Personally, I feel that the usual chatter on the topic tends to be misguided. For me, professionalism is more reflected by individual behaviors.

Two related issues were raised on which I have opinions I would like to share.

First, the ongoing discussion between Environmental Engineer as a four-year degree versus a graduate degree was raised. I understand and endorse the concept that it takes more than a B.S. level of education to be a well-trained environmental engineer; however, I'm not clear on why this means that we must send students through a B.S. program in some other engineering discipline before we train them as environmental engineers. It was suggested that we consider denying ABET accreditation to B.S. programs in Environmental Engineering, and thus send a clear message that we don't support this approach.

I believe that ABET should follow and not lead. I don't feel comfortable using ABET as an aggressive tool to assert the public position of one or two professional associations.

The second point was that I heard Phil Hall, CEO of CH2M Hill, say that he sees a value in the global marketplace for a Doctoral degree. When I was in school, my decision as to whether to complete a Ph.D. program was made on the basis of whether I wanted to spend my life teaching. The range of career options which would benefit from a Doctoral degree appears to have grown.

I think that if I were in a dynamic entrepreneurial university, I would be tempted to develop a Doctor of Engineering program as a "return to school" program for career engineers. I would negotiate with some larger engineering companies who could share the cost. If programs like this took hold over a few decades, then we might define an indisputable professional level of engineers and eventually the debate on professionalism could simmer down.

About the Author *— Roger J. Dolan, P.E., DEE is the Chief Engineer at the Central Contra Costa Sanitary District in Martinez, California.*

Conference Summary

Clifford W. Randall

I now wish to summarize and share with you what I thought I heard during the sessions of this Conference. To begin with, I believe the spirit of the Conference could be summarized by a statement made by one of today's speakers, "What we do today creates the future". With this thought uppermost in mind, I will attempt to summarize and comment.

The consensus of the Conference speakers was that there are several major trends underway that will have a significant impact upon Environmental Engineering Education. I was able to identify those that arose more than once, and a list of them follows:

- Globalization.
- Increasing Importance of Developing Countries.
- Activities Market Driven rather than Regulatory Driven.
- Privatization of Water & Wastewater Facilities.
- Sustainable Development/Green Engineering.
- Value Assessment of Engineering Designs.
- Broad Definition of Environmental Engineering.
- Flexible Accreditation of Educational Programs
- Outcomes Assessment of Educational Programs

No doubt this list is not exhaustive, but there does seem to be a reasonable consensus that they are genuine trends. The question for Environmental Engineering Educators is, what changes should be made to our curricula and teaching techniques to properly prepare our students for the future, given these trends?

There also were some criticisms that were heard repeatedly. The following were the four primary ones heard by this writer:

- Engineering Education is not working.
- Environmental Engineers have abdicated Leadership.
- The trend towards the BS in Environmental Engineering is potentially detrimental.
- More Gender and Ethnic Diversity is needed in Environmental Engineering, AEEP membership, and on the programs of conferences and workshops organized by AEEP.

We need to examine these criticisms to see if we believe they are valid, and, if so, what action should be taken to make positive changes.

Even though several speakers stated that engineering education was not working and that changes are needed, several, including some of those that said it currently was not working, said that engineering education in the USA is the best in the world. As evidence they pointed out that most of the world's engineers want to be educated at USA universities.

Comments regarding gender and ethnic diversity, and the use of sexist comments by speakers, were expressed personally rather than from the podium. With respect to gender diversity, it was mentioned that the Workshop held immediately before the Conference had good diversity, but the first two days of the Conference did not. This was partially rectified by the last two half-day sessions of the Conference, and the final percentage of women on the program was only slightly less that the percentage in attendance. The lack of African-Americans in the profession and on the program was expressed as a continuing cause of concern, and one that deserves action. Strong objections were voiced about remarks made by one or more of the speakers that were believed to be demeaning to women.

Several speakers discussed the skills, knowledge and experiences that students should receive from an Environmental Engineering education. The following list was compiled as representative of the consensus:

- Broad based knowledge of fundamentals for a lifetime of learning.

- Thorough knowledge and use of the "scientific approach".
- Communications skills.
- Creativity.
- Computer skills.
- Team skills.
- Economic analysis skills.
- Socio-Political literacy.
- More contact with practitioners.
- Firm grounding in ethics.

While the educational needs were generally discussed by the speakers in substantial detail, both speakers and attendees mentioned some concerns which were not discussed in detail, but seemed to represent concerns of a substantial fraction of those in attendance. Three were identified. They are:

1. Is there a genuine marketplace for Environmental Engineering graduates at the B.S. level? Or are they chronically over-qualified or under-qualified for the positions they occupy?
2. Are we producing too many Environmental Engineers for the marketplace? At the M.S. level? At the Ph.D. level?
3. Are the current and proposed licensing procedures/processes consistent with current educational practices?

While summarizing the proceedings of the Conference, several challenges for the Environmental Engineering Education profession were perceived and identified. The final list follows:

- Development of diverse, unique Environmental Engineering Programs.
- Educate for both the Global Market and the Domestic Market.
- Integrate Environmental Engineering concepts into other Engineering curricula.
- Satisfactorily interface the BS & MS degrees in Environmental Engineering.
- Improve/Increase linkages between Academia and Practitioners.
- Increase gender and ethnic diversity in the environmental engineering profession.
- Implement outcome assessment of environmental engineering education at all levels.

This is an imposing list of challenges, but I believe it is a genuine set of challenges that we, as a profession, need to accept and prepare for if we are to meet society's environmental needs during the twenty-first century. I also believe that we are capable of meeting these challenges, but only if there is a joint, closely-coordinated effort by academicians and practitioners. Nowhere is this type of coordination and interaction more needed than in the development of accreditation requirements and procedures for academic programs. It is essential that these criteria be jointly developed rather than developed by one faction and then imposed on the other. The cooperative approach also needs to be extended to the certification and licensing criteria. There needs to be close coordination between educational content and licensing/certification requirements. It makes no sense to educate on one basis and then certify/license on another. These need to be closely coordinated efforts.

The last thing that I would like to share with you that I have heard at this meeting is this: *"Limited information access restricts learning, innovation and productivity!"* Consequently, one of the challenges for those of us in both the educator's and practitioner's fields is to make information more accessible. By way of example, I would like to use the Chesapeake Bay Project, which I have been working with since its beginning in 1985. This is a very large, comprehensive ecosystem engineering project. I'm one of the few engineers involved at its decision-making core. Most of the people I have to work with are scientists, managers and politicians, and political considerations determine or strongly affect most decisions. However, the single factor that has most limited our progress has been the availability of information, particularly scientific information. Our biggest challenge has been that of making the experimental, management and monitoring data collected available to everybody involved. We have not yet solved this problem but we are still hopeful of doing so. Clearly innovative ways of making information quickly and easily available to all parties are needed. This needs to become part of the education process as well.

In closing, I will respond to a statement from the floor by Dr. Aarne Vesilind of Duke University. He commented upon my selecting undergraduate degrees in Environmental Engineering as a concern, and noted that this should not be concluded as a sense of the Conference. I agree with Dr. Vesilind's remarks. I did not mean it to be taken as a conclusion or "sense" of the Conference. I simply noted that it was a concern voiced by some, and, while they are probably in the minority, they are a sizable fraction of those present. As noted by Dr. Vesilind, there were a lot of people in attendance at the Conference who would support very strong undergraduate Environmental Engineering programs, as well as graduate programs. I am not going on record at this time as being opposed to undergraduate Environmental Engineering degrees, but I am suggesting that we, as a profession, need to closely examine this issue in the near future.

***About the Author** — Clifford W. Randall is the President of AEEP.*

SECTION 8

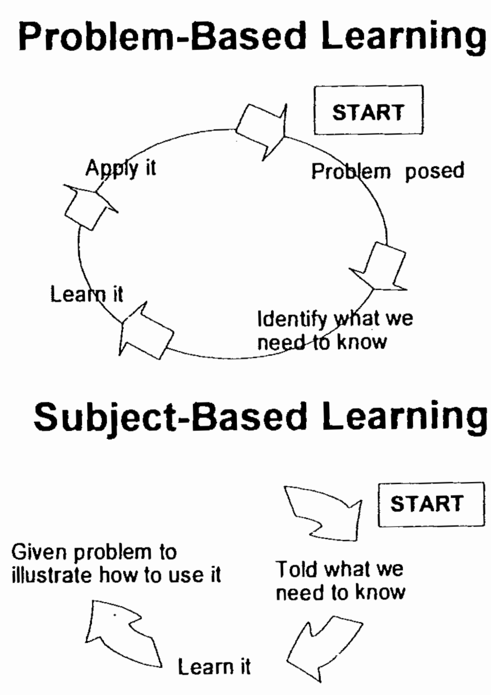
Teaching Keynote Paper

Problem-Based Cooperative Learning

Karl A. Smith

Problem-based learning(PBL) results from the process of working toward the understanding or resolution of a problem. The process of problem-based learning is shown in Figure 25-1 and is contrasted with subject-based learning (Woods 1994).

Figure 25-1
Process of Problem-Based Learning



Problem-based learning is very suitable for engineering (as it is for medicine, where it is currently used) because it helps students develop skills and confidence for formulating problems they've never seen before. PBL is typically very difficulty for faculty because few have experienced this pedagogical approach and most were successful in the "normative professional curriculum" model (Schön 1987):

1. Teach the relevant basic science.
2. Teach the relevant applied science.
3. If you have time and for those who are still around, give a practicum to help students connect the relevant basic and applied science to practice.

The intellectual activity of building models to solve problems — an explicit activity of constructing or creating the qualitative or quantitative relationships — helps students understand, explain, predict, etc. (Smith and Starfield 1993; Starfield, Smith, and Bleloch 1994). The process of building models together in face-to-face interpersonal interaction results in learning that is difficult to achieve in any other way.

Problem-based learning may be implemented in a variety of ways, for example the whole-class Socratic dialogue approach where the professor poses questions and then calls on unsuspecting individuals to answer them. This paper focusses on PBL approaches that involved students in high-level interpersonal interaction via the cooperative learning (CL) model of instruction.

Cooperation is working together to accomplish shared goals. Within cooperative activities individuals seek outcomes that are beneficial to themselves and beneficial to all other group members. *Cooperative learning* is the instructional use of small groups so that students work together to maximize their own and each other's learning (Johnson, Johnson, and Smith 1991). Carefully structured cooperative learning involves people working in teams to accomplish a common goal, under conditions that involve both *positive interdependence* (all members must cooperate to complete the task) and *individual and group accountability* (each member is accountable for the complete final outcome).

There are many ways to implement cooperative learning in engineering classrooms. Informal cooperative learning groups, formal cooperative learning groups, and cooperative base groups are the most common. Each has a place in providing opportunities for students to be intellectually active and personally interactive both in and outside the classroom. Informal cooperative learning is commonly used in predominately lecture classes or by faculty just starting to experiment with alternative pedagogy (Smith and Waller 1996). Formal cooperative learning can be used in content intensive classes where the mastery of conceptual or procedural material is essential; however, many faculty find it easier to start in recitation or laboratory sections or design project courses. Base groups are long-term cooperative learning groups whose principal responsibility is to provide support and encouragement for all their members; that is, to ensure that each member gets the help he or she needs to be successful in the course and in college. The basics of base groups are described by Treisman (1992) and the implementation of base groups in engineering colleges is being pioneered at California State University-Los Angeles, California State University-Pomona, the University of Cincinnati, and numerous other schools.

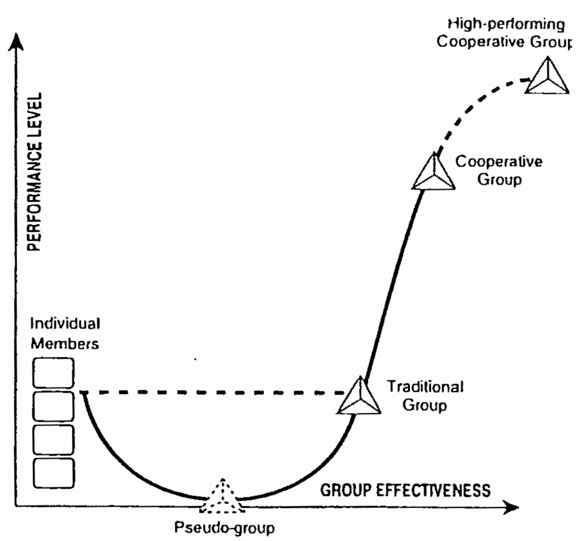
Informal cooperative learning groups are temporary, ad hoc groups that last from a few minutes to one class period. They are used to focus students' attention on the material to be learned, set a mood conducive to learning, help organize in advance the material to be covered in a class session, ensure that students cognitively process the material being taught, and provide closure to a class session. They are often organized so that students engage in *focused discussions* before and after a lecture and interspersing *turn-to-your-partner* discussions throughout a lecture. Informal cooperative learning groups help counter what is proclaimed as the main problem of lectures: "The information passes from the notes of the professor to the notes of the student without passing through the mind of either one."

Base Groups are long-term, heterogeneous cooperative learning groups with stable membership whose primary responsibility is to provide each student the support, encouragement, and assistance he or she needs to make academic progress. Base groups personalize the work required and the course learning experiences. These base groups stay the same during the entire course and longer if possible. The members of base groups should exchange phone numbers and information about schedules as they may wish to meet outside of class. When students have successes, insights, questions or concerns they wish to discuss; they can contact other members of their base group. Base groups typically manage the daily paperwork of the course through the use of group folders.

The focus of this short article is on the design and implementation of problem-based learning in formal cooperative learning groups, since they are probably the most difficult to implement and they have the greatest potential for affecting positive change. *Formal cooperative learning groups* are more structured than informal, are given more complex tasks, and typically stay together longer.

There is nothing magical about teamwork. For example, some types of learning teams increase the quality of classroom life and facilitate student learning. Other types of teams hinder student learning and create disharmony and dissatisfaction with classroom life. To use cooperative learning effectively, you must know what is and what is not a cooperative group.

Figure 25-2
Types of Teams



There are many types of teams that can be used in classrooms (Figure 25-2). Cooperative learning is just one of them. When you use instructional groups, you must ask yourself *"What type of group am I using?"* The following checklist may be helpful in answering that question.

1. Pseudo-Learning Group: Students are assigned to work together but they have no interest in doing so. They believe they will be evaluated by being ranked from the highest performer to the lowest performer. While on the surface students talk to each other, under the surface they are competing. They see each other as rivals who must be defeated, block or interfere with each other's learning, hide information from each other, attempt to mislead and confuse each other, and distrust each other. Students would achieve more if they were working alone.

2. Traditional Classroom Learning Group: Students are assigned to work together and accept that they must do so. Assignments are structured, however, so that very little joint work is required. Students believe that they will be evaluated and rewarded as individuals, not as members of the group. They interact primarily to clarify how assignments are to be done. They seek each other's information, but have no motivation to teach what they know to their groupmates. Helping and sharing is minimized. Some students loaf, seeking a free ride on the efforts of their more conscientious groupmates. The conscientious members feel exploited and do less. The result is that the sum of the whole is more than the potential of some of the members, but the more hard working and conscientious students would perform higher if they worked alone.

3. Cooperative Learning Groups: Students are assigned to work together and, given the complexity of the task and the necessity for diverse perspectives, they are relieved to do so. They know that their success depends on the efforts of all group members. The group format is clearly defined. First, the group goal of maximizing all members' learning provides a compelling common purpose that motivates members to roll up their sleeves and accomplish something beyond their individual achievements. Second, group members hold themselves and each other accountable for doing high quality work to achieve their mutual goals. Third, group members work face-to-face to produce joint work-products. They do real work together. Students promote each other's success through helping, sharing, assisting, explaining, and encouraging. They provide both academic and personal support based on a commitment to and caring about each other. Fourth, group members are taught teamwork skills and are expected to use them to coordinate their efforts and achieve their goals. Both task and teambuilding skills are emphasized. All members share responsibility for providing leadership. Finally, groups analyze how effectively they are achieving their goals and how well members are working together. There is an emphasis on continual improvement of the quality of learning and teamwork processes.

4. High-Performance Cooperative Learning Group: This is a group that meets all the criteria for being a cooperative learning group and outperforms all reasonable expectations, given its membership. What differentiates the high-performance group from the cooperative learning group is the level of commitment members have to each other and the group's success. Jennifer Futernick, who is part of a high-performing, rapid response team at McKinsey & Company, calls the emotional binding of her teammates together a form of love (Katzenbach and Smith 1993). Ken Hoepner of the Burlington Northern Intermodal Transport Team (also described in Katzenbach and Smith 1993) stated: "Not only did we trust each other, not only did we respect each other, but we gave a damn about the rest of the people on this team. If we saw somebody vulnerable, we were there to help." Members' mutual concern for each other's personal growth enables high-performance cooperative groups to perform far above expectations, and also to have lots of fun. The bad news about high-performance cooperative learning groups is that they are rare. Most groups never achieve this level of development.

Essential Elements That Make Cooperative Learning Work

Well-structured cooperative learning groups are differentiated from poorly structured ones on the basis of five essential elements. These essential elements should be carefully structured within all levels of cooperative efforts. The five essential elements are as follows:

1. Positive Interdependence: The heart of cooperative learning is positive interdependence. Students must believe that they are linked with others in a way that one cannot succeed unless the other members of the group succeed (and vice versa). Students are working together to get the job done. In other words, students must perceive that they "sink or swim together." In a problem-solving session, positive interdependence is structured by group members (1) agreeing on the answer and solution strategies for each problem (goal interdependence) and (2) fulfilling assigned role responsibilities (role interdependence). Other ways of structuring positive interdependence include having common rewards, shared resources, or a division of labor.

2. Face-to-Face Promotive Interaction: Once a professor establishes positive interdependence, he or she must ensure that students interact to help each other accomplish the task and promote each other's success. Students are expected to explain orally to each other how to solve problems, discuss with each other the nature of the concepts and strategies being learned, teach their knowledge to classmates, explain to each other the connections between present and past learning, and help, encourage, and support each other's efforts to learn. Silent students are uninvolved students who are not contributing to the learning of others or themselves.

3. Individual Accountability/Personal Responsibility: The purpose of cooperative learning groups is to make each member a stronger individual in his or her own right. Students learn together so that they can subsequently perform better as individuals. To ensure that each member is strengthened, students are held individually accountable to do their share of the work. The performance of each individual student is assessed and the results given back to the individual and perhaps to the group. The group needs to knows who needs more assistance in completing the assignment, and group members need to know they cannot "hitch-hike" on the work of others. Common ways to structure individual accountability include giving an individual exam to each student, randomly calling on individual students to present their group's answer, and giving an individual oral exam while monitoring group work.

4. Teamwork Skills: Contributing to the success of a cooperative effort requires teamwork skills. Students must have and use the needed leadership, decision-making, trust-building, communication, and conflict-management skills. These skills have to be taught just as purposefully and precisely as academic skills. Many students have never worked cooperatively in learning situations and, therefore, lack the needed teamwork skills for doing so effectively.

5. Group Processing: Professors need to ensure that members of each cooperative learning group discuss how well they are achieving their goals and maintaining effective working relationships. Groups need to describe what member actions are helpful and unhelpful and make decisions about what to continue or change. Such processing enables learning groups to focus on group maintenance, facilitates the learning of collaborative skills, ensures that members receive feedback on their participation, and reminds students to practice collaborative skills consistently. Some of the keys to successful processing are allowing sufficient time for it to take place, making it specific rather than vague, maintaining student involvement in processing, reminding students to use their teamwork skills during processing, and ensuring that clear expectations as to the purpose of processing have been communicated.

In order for professors to use cooperative learning routinely, they must identify course routines and generic lessons that repeat over and over again and structure them cooperatively. Problem-solving lessons are one good example of a repeated practice.

Problem-Based Cooperative Learning

Formal cooperative learning groups may last from one class period to several weeks to complete specific tasks and assignments — such as decision making or problem solving, writing a report, conducting a survey or experiment, preparing for an exam, or answering questions or homework problems. Any course requirement may be reformulated to be cooperative. In formal cooperative groups the professor should:

1. Specify the objectives for the lesson. In every engineering lesson there should be an academic objective specifying the concepts and strategies to be learned and a teamwork objective specifying the interpersonal or small group skill to be used and mastered during the lesson.
2. Make a number of instructional decisions. The professor has to decide on the size of groups, the method of assigning students to groups, how long the groups stay together, the roles the students will be assigned, the materials needed to conduct the lesson, and the way the room will be arranged.
3. Explain the task and the positive interdependence. The professor needs to clearly define the assignment, teach the required concepts and strategies, specify the positive interdependence and individual accountability, give the criteria for success, and explain the expected teamwork skill to be engaged in.
4. Monitor students' learning and intervene within the groups to provide task assistance or to increase students' teamwork skills. The professor systemically observes and collects data on each group as it works. When it is needed, the professor intervenes to assist students in completing the task accurately and in working together effectively.
5. Evaluate students' learning and help students process how well their group functioned. Students' learning is carefully assessed and their performances are evaluated. The professor provides time and a structure for members of each learning group to process how effectively they have been working together. A criteria-referenced evaluation procedure must be used, that is, grading must *not* be curved.

A typical format for problem-based cooperative learning is shown in Figure 25-3. The format illustrates the professor's role in a formal cooperative learning lesson and shows how the five essential elements are incorporated.

Figure 25-3
Problem-Based Cooperative Learning Format

TASK: (Solve the problems)

INDIVIDUAL: Estimate answer. Note strategy.

COOPERATIVE: One set of answers from the group, strive for agreement, make sure everyone is able to explain the strategies used to solve each problem.

EXPECTED CRITERIA FOR SUCCESS: Everyone must be able to explain the strategies used to solve each problem.

EVALUATION: Best answer within available resources or constraints.

INDIVIDUAL ACCOUNTABILITY: One member from any group may be randomly chosen to explain (a) the answer and (b) how to solve each problem.

EXPECTED BEHAVIORS: Active participating, checking, encouraging, and elaborating by all members.

INTERGROUP COOPERATION: Whenever it is helpful, check procedures, answers, and strategies with another group.

Cooperative problem-solving groups typically consist of two to four members. Group membership is randomly selected and typically changes with each assignment. Problem-solving group work follows a format such as:

1. Groups formulate and solve problems. Each group will place its formulation and solution on an overhead transparency or on paper.
2. Randomly selected students will present their group's model and solution.

3. Discussion of formulation and solution. All members of the class will be expected to discuss and question all models.
4. Each group will prepare and submit a project report, and process its effectiveness as a group.

PBCL and Engineering Design

Problem-based cooperative learning is also a terrific format for helping students learn how to do engineering design. Design is routinely listed as essential for engineering students. ABET defines engineering design as "the process of devising a system, component or process to meet a desired need". A 1986 NSF Workshop Committee described the importance of design more emphatically: "Design in a major sense is the essence of engineering; it begins with the identification of a need and ends with a product or system in the hands of a user. It is primarily concerned with synthesis rather than the analysis which is central to engineering science. Design, above all else, distinguishes engineering from science (Hancock (1986), National Science Foundation Workshop). A colleague at the University of Minnesota raised the stakes even higher: "Design defines engineering. It's an engineer's job to create new things to improve society. It's the University's obligation to give students fundamental education in design (Durfee 1994).

Design is often presented as a rational, algorithmic process whereby students follow a series of prescribed steps to reach an end product. Recent work on engineering design indicates that it's not nearly as rational process as we once naively thought. Ferguson (1992), for example, wrote that "Those who observe the process of engineering design find that it is not a totally formal affair, and that drawings and specifications come into existence as a result of a social process. The various members of a design group can be expected to have divergent views of the most desirable ways to accomplish the design they are working on. As Louis Bucciarelli, an engineering professor who has observed engineering designers at work, points out, informal negotiations, discussions, laughter, gossip, and banter among members of a design group often have a leavening effect on its outcome".

Recent work on engineering design indicates that design is a more social process than we once thought. Larry Leifer (Stanford Center for Design Research) claims that engineering design is "a social process that identifies a need, defines a problem, and specifies a plan that enables others to manufacture the solutions." Two of Leifer's recent Ph.D. graduates — Scott Minneman (*The social construction of a technical reality: Empirical studies of group engineering design practice*) and John Tang (*Listing, drawing, and gesturing in design: A study of the use of shared workspaces by design teams*) — argue that design is fundamentally a social activity. They describe practices such as "negotiating understanding," "conserving ambiguity," "tailoring engineering communications for recipients," and " manipulating mundane representations." Using predominantly ethnographic procedures they conduct research using what they describe as a "rigorously subjective methodology." Some of the cutting edge of design research (being conducted at Stanford and Xerox Palo Alto Research Lab) is now confirming what Billy Koen (1986) described 10 years ago — there is no simple or guaranteed approach to engineering design (no algorithms, in other words). There are, however, many very good heuristics — apply science where appropriate, use an engineering morphology, use feedback to stabilize design, make small changes in the state-of-the-art.

The implications of Leifer and Ferguson work for the teaching of design is profound! Essentially it means that we must work in a different way, that we must develop high performance teams of students, and that our role must become one of facilitator rather than one who professes. Donald Schön (1987) described designing and the professor's role in the process as follows:

> Designing, both in its narrower architectural sense and in the broader sense in which all profession practice is designlike, must be learned by doing. However much students may learn about designing from lectures or readings, there is a substantial component of design competence — indeed, the heart of it — that they cannot learn in this way. A designlike practice is learnable but is not teachable by classroom methods. And when students are helped to learn design, the interventions most useful to them are more like coaching than teaching — as in a reflective practicum.

Learning to think like an engineer means learning to do both analysis and synthesis both alone and with a group of team members. Learning that is informal, social, and focused on meaningful problems helps create "insider knowledge." Gaining insider knowledge

— learning to speak, write, and think engineering — is a major part of becoming a member of a community of practice (Seely, Brown, and Duguid 1991).

Support for Cooperative Learning

During the past 90 years, nearly 600 experimental and over 100 correlational studies have been conducted comparing the effectiveness of cooperative, competitive, and individualistic efforts. These studies have been conducted by a wide variety of researchers in different decades with different age subjects, in different subject areas, and in different settings. More is known about the efficacy of cooperative learning than about lecturing, the fifty-minute class period, the use of instructional technology, or almost any other aspect of education. From this research you would expect that the more students work in cooperative learning groups the more they will learn, the better they will understand what they are learning, the easier it will be to remember what they learn, and the better they will feel about themselves, the class, and their classmates. The multiple outcomes studied can be classified into three major categories: achievement/productivity, positive relationships, and psychological health. Cooperation among students typically results in (a) higher achievement and greater productivity, (b) more caring, supportive, and committed relationships, and (c) greater psychological health, social competence, and self-esteem. A summary of the studies conducted at the higher education level may be found in Johnson, Johnson, and Smith (1991a, 1991b). A comprehensive review of all studies and meta-analyses of their results is available in Johnson and Johnson (1989).

Cooperative learning researchers and practitioners have shown that positive peer relationships are essential to success in college. Isolation and alienation are the best predictors of failure. Two major reasons for dropping out of college are failure to establish a social network of friends and classmates, and failure to become academically involved in classes (Tinto 1994). Working together with fellow students, solving problems together, and talking through material together has other benefits as well (McKeachie et al. 1986):

> Student participation, teacher encouragement, and student-student interaction positively relate to improved critical thinking. These three activities confirm other research and theory stressing the importance of active practice, motivation, and feedback in thinking skills as well as other skills. This confirms that discussions...are superior to lectures in improving thinking and problem solving.

W. Edwards Deming (1993) recently made a compelling case for the importance of cooperation and interdependence:

> We have grown up in a climate of competition between people, teams, departments, divisions, pupils, schools, universities. We have been taught by economists that competition will solve our problems. Actually, competition, we see now, is destructive. It would be better if everyone would work together as a system, with the aim for everybody to win. What we need is cooperation and transformation to a new style of management...Competition leads to loss. People pulling in opposite directions on a rope only exhaust themselves: they go nowhere. What we need is cooperation. Every example of cooperation is one of benefit and gains to them that cooperate. Cooperation is especially productive in a system well managed.

Myron Tribus (1996) maintains that teams are essential for developing engineering skills and competencies:

> The main tool for teaching wisdom and character is the group project. Experiences with group activities, in which the members of the groups are required to exhibit honesty, integrity, perseverance, creativity and cooperation, provide the basis for critical review by both students and teachers. Teachers will need to learn to function more as coaches and resources and less as givers of knowledge.

Conclusions

The importance of teamwork and design are increasing in engineering schools. The article advocates for the use of problem-based cooperative as an effective way of helping students learn to work as a member of a high performance team and do design. There are some precautions, however. Many educators who believe that they are using cooperative learning are, in fact, missing its essence. There is a crucial difference between simply putting students in groups to learn and in structuring cooperation among students. Cooperation is *not* having students sit side-by-side at the same table to talk with each other as they do their individual assignments. Cooperation is *not* assigning a report to a group of students where one student does all the work and the others put their names on the product as well. Cooperation is *not* having students do a task individually with instructions that the ones who finish first are to help the slower students. Cooperation is much more than being physically near other students, discussing material with other students, helping other students, or sharing material among students, although each of these is important in cooperative learning.

To be cooperative, a group must have clear positive interdependence, members must promote each other's learning and success face-to-face, hold each other personally and individually accountable to do his or her fair share of the work, appropriately use the interpersonal and small-group skills needed for cooperative efforts to be successful, and process as a group how effectively members are working together. These five essential components must be present for small group learning to be truly cooperative.

Cooperative learning can be used to (a) teach specific content, problem-solving skills, and design skills (formal learning groups), (b) ensure active cognitive processing during a lecture (informal learning groups), and (c) provide long-term support and assistance for academic progress (base groups). When used in combination, these formal, informal, and base cooperative learning groups provide an overall structure to teamwork in engineering classes.

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APPENDICES

Appendix A

Curriculum at the M.S. Level in the Water Resources Engineering Program
University of North Carolina
Department of Environmental Sciences and Engineering

Requirements

A minimum of 30 credit hours is required for the MSEE degree, at least 24 or which must be through formal course-work. The remaining 6 credit hours can be satisfied by the required M.S. report. Specifics are provided in the Graduate School catalog.

Core Courses

Each MSEE student in Water Resources Engineering (WRE) must select 15 credit hours of coursework from the list of core engineering classes in Table A-1.

Elective Courses

A list of elective courses typically taken by WRE students is given in Table A-2.

Statistics

Students are also required to take one class in statistics. The most common choices are:

BIOS 135	Probability and Statistics
BIOS 145	Principles of Experimental Analysis

Areas of Specialization

While there is considerable flexibility in allowing each student to structure an academic program that best suits his or her needs, we recognize that students often desire to pursue coursework in specific areas of concentration. Areas of specialization and suggested courses within each are listed in Table A-3.

Table A-1
Core Engineering Classes

ENVR 171	Reactor and Mass Transport Principles (3) (F)
ENVR 176	Introduction to Groundwater Engineering (3) (F)
ENVR 176L	Subsurface Process Laboratory (2) (Sp)
ENVR 217	Systems Analysis in Environmental Planning (3) (Sp)
ENVR 245	Air Pollution Control (3) (Sp) (alternate years)
ENVR 247	Microenvironmental Air Flow Modeling (3) (F)
ENVR 272	Design of Water Systems (3) (Sp)
ENVR 273	Water and Wastewater Treatment Plant Design (3) (Su)
ENVR 274	Physical/Chemical Treatment Processes (2) (Sp)
ENVR 275	Biological Treatment Processes (2) (Sp)
ENVR 276	Industrial Waste Treatment (3) (F) (alternate years)
ENVR 277	Treatment Process Laboratory (2) (Sp)
ENVR 278	Geostatistics for Spatial/Temporal Environmental Phenomena (3) (F)
ENVR 279	Random Field Modeling of Physical Processes (3) (Sp)
ENVR 280	Multiphase Transport Phenomena (3) (F)
ENVR 281	Applied Numerical Modeling (3) (Sp)
ENVR 284	Water Resources Planning and Policy Analysis (3) (F)

Table A-2
Elective Courses

ENVR 122	Chemical Equilibria in Natural Waters
ENVR 122L	Aquatic Chemistry Laboratory
ENVR 123	Organic Materials in Natural Waters
ENVR 124	Environmental Analytical Chemistry
ENVR 132	Limnology and Water Pollution
ENVR 134	Ecological Microbiology
ENVR 135	Biology in Environmental Science
ENVR 145	Introduction to Aerosol Science
ENVR 219	Water Policy in Lesser Developed Countries
ENVR 238	Microbial Degradation of Xenobiotics
ENVR 241	Principles of Industrial Ventilation
ENVR 252	Environmental Risk Assessment
ENVR 255	Management of Hazardous Wastes
ENVR 282	Public Investment Theory and Techniques
ENVR 283	Natural Resource Law and Policy
ENVR 321	Reduction/Oxidation Processes in the Aquatic Environment
ENVR 322	Photochemical Processes in the Aquatic Environment
ENVR 323	Advanced Oxidation Processes for Water and Wastewater Treatment
ENVR 324	Chemistry of Humic Substances
MASC 151	Fluid Dynamics
MATH 128	Mathematical Methods for the Physical Sciences I
MATH 129	Mathematical Methods for the Physical Sciences II
MATH 191	Applied and Computational Mathematics I
MATH 192	Applied and Computational Mathematics II
ORSA 181	Deterministic Models in Operations Research
ORSA 183	Stochastic Models in Operations Research
PLAN 210	Economic Analysis for Public Policy Planning
ECON 101a	Intermediate Theory: Price and Distribution
ECON 111	Resource and Environmental Economics
ECON 272	Econometrics
CHE 590o	Pollution Prevention: The Future of Waste Minimization (NCSU)

Table A-3
Suggested Programs of Study

Hydrology and Contaminant Transport	Water Resources Systems Analysis and Planning	Industrial and Hazardous Wastes	Water and Wastewater Treatment Processes
Suggested Core Courses			
ENVR 171	ENVR 176	ENVR 171	ENVR 171
ENVR 176	ENVR 217	ENVR 176	ENVR 273
ENVR 278	ENVR 272	ENVR 245	ENVR 274
ENVR 279	ENVR 273	ENVR 274	ENVR 275
ENVR 280	ENVR 278	ENVR 275	ENVR 276
ENVR 281		ENVR 276	ENVR 277
Typical Electives			
ENVR 122	ENVR 219	ENVR 122	ENVR 122
ENVR 135	ENVR 282	ENVR 134	ENVR 132
MATH 128	PLAN 210	ENVR 238	ENVR 135
MATH 129	ORSA 181	ENVR 252	ENVR 238
MATH 191	ORSA 183	ENVR 255	ENVR 255
MATH 192	ECON 272	CHE 590o	

Students are advised to consult the Graduate School catalog for a complete listing and description of courses.

Appendix B

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