PERSPECTIVES

On the Professions

A periodical of the Center for the Study of Ethics in the Professions (CSEP), Illinois Institute of Technology

HUB Mezzanine, Room 204, 3241 S. Federal Street, Chicago, IL 60616-3793
Tel: 312.567.3017, Fax: 312.567.3016, email: csep@iit.edu

Vol. 10, No. 2 January 1991

"What is Good Science? What is Good Engineering"

Michael Davis, Editor, CSEP, Illinois Institute of Technology

The consequences of bad science are many. Bad science can send scientists on a wild goose chase, at least for a time, and use up money and resources. Bad science can also mislead the general public about facts, or about the certainty or uncertainty of our current knowledge in some field. Bad science can find its way into public policy or economic decisions. The worst cases of bad science involve fraud with immediate consequences for the safety of the public, such as false claims about the efficacy of a drug or the toxicity of a substance. But in general, the product of science is knowledge, and knowledge can be used for good or evil.

Bad engineering is of more immediate danger to the public. Can openers that cut off fingers, cars that blow up, nuclear power plants that melt down, can maim, kill, or terrify innocent people. The ultimate cause may be some fault in calculations or design, or simply neglecting to take into consideration that humans are involved. Good engineering has to outsmart the human capacity for mistakes.

Some major disasters that look like products of bad science or bad engineering may in fact have another cause. For example, the warped mirror of the Hubble telescope was the result not of bad science or even bad engineering: politicians and bureaucrats made a budgetary decision not to test the telescope before sending it up and so missed a technician's error.

We are shocked by fraud in science and failures in engineering. Why? The answer is that we take for granted good science and good engineering. But what is good science? What is good engineering? Do scientists and engineers have different ideas about this, or is there a consensus? Can it be spelled out? How can students be taught to do good science or good engineering?

With a science and engineering faculty strongly committed to both research and teaching, IIT seems to be a good place to discuss these questions. Such a discussion took place this fall as part of IIT's Centennial, sponsored by the Program on Science and Technology in Context, the Center for the Study of Ethics in the Professions, and the Department of Civil Engineering. This issue of *Perspectives* is drawn from that discussion. Our first section, *The Importance of Being Earnest*, consists of three scientists' views of good science: Bob Filler (chemistry), Ben Stark (biology), and Porter Johnson (physics).

Good engineering is discussed in the second section, *Doing the Right Thing*, by Hamid Arastoopour (chemical engineering), Janine Larsen (electrical and computer engineering), and Hassan Nagib (mechanical and aerospace engineering).

In the third section, *The Good, the Bad, and the Ugly*, Sid Guralnick (civil engineering) argues that engineering is a strikingly different intellectual activity from science, strongly dependent on imagining what does not yet exist. The next section, *Close Encounters*, further clarifies the relation between science and engineering.

Professors of science and engineering try to teach how to do good work. *Things Change* takes up the question of how to teach good science and good engineering in fields where change is both constant and profound. The discussion concludes with some thoughts about funding research, *For a Few Dollars More*.

Much remains to be said. The important thing is to continue the discussion. IIT's Centennial panel made a good start.

"The Importance of Being Earnest: Three Scientists on "Good Science""

Bob Filler

Good science is an intellectually rewarding enterprise, characterized by fun and frustration in search of new knowledge, pursued with commitment, enthusiasm and vigor. It's an exciting, challenging, and stimulating endeavor. Its hallmark is thoroughness in execution and intellectual honesty. Let me elaborate on these points.

Thoroughness in execution requires a clear statement of purpose, a comprehensive survey of what is known on the subject in the literature, and a well-designed plan of attack. These cannot be sloughed over. These must be done first.

In experimental chemistry, for example, which I've been involved in since 1943, we should expect a well crafted procedure, careful observation, and a dedicated unbiased recording of the events and results, written at the time, not later.

I'd like to emphasize this last point, observation. Students don't always realize that it isn't good enough to set up the experiment and take down what is observed. You should be looking very closely. I learned that the hard way.

Many years ago, when I was a graduate student, I discovered something that had nothing to do with the research I was doing, something small. I went to various professors. They said, "Don't waste your time, get on with the show." So I dropped it. Two years later, a young assistant professor at Georgia Tech elaborated on the type of observation I made and became famous. I don't know if he became rich-he is a professor-but he certainly established a name for himself. If you see something out of the ordinary, follow it. Those tangents are sometimes where the interesting science is. Another example:

You've heard of Teflon. That was serendipity, finding the most delightful thing in the most unexpected place. That discovery, absolutely accidental, led to a remarkable advance in polymer technology. Many of you use Nutrasweet. This, of course, is a di-peptide (two amino acids put together) called aspartame. It was discovered in Skokie about fifteen years ago A researcher went home and noticed that his food was sweet. His wife said, "I put nothing in it:" He said, "Oh yes you did." It turned out that he hadn't washed his hands completely when he left the lab. He went back and realized he had discovered a non-caloric synthetic sweetener. His discovery has had a significant impact on nutrition.

Now, about intellectual honesty. Many of you have heard about scientists who falsified results, usually under pressure, for fame or fortune or both. I cannot over-emphasize this particular point to students. It is the easiest thing in the world to fall into. Yesterday, Ireceived a copy of *R & D Magazine*. One article reports that of ninety-nine industrial chemists who responded to a survey, about half reported that they were personally acquainted with falsifying data. They didn't say if they were the ones who did it, only that they knew of an industrial laboratory where someone had committed fraud in order to keep profits high-in order to beat out somebody else.

So, I'm concluding with just two simple messages: first, observe carefully and pursue any observation that looks important; and second, keep your intellectual honesty.

Porter Johnson

Good science is novel. New insights are introduced, new discoveries are made, new models are constructed, or new views of the world are created-new paradigms. A great discovery creates an industry. Perhaps a physical industry, such as micro-electronics, which came as a result of the discovery of the transistor. Or, perhaps, just an industry of people who are studying the problem in question. Great research papers catalyze other significant research papers and many people begin to work on the subject as a result of a breakthrough.

Good science is cumulative as well as novel. Good science is reproducible. All important scientific discoveries will be checked somehow, somewhere, someday. If it's not important, you don't have to worry about whether it's checked. But if it's at all important, it's going to be checked. If you make a significant claim in science, someone else is going to check your work.

Good science is open. Secret recipes, secret procedures, secret ideas are held in suspicion by scientists and for good reason, because usually they don't work. Good science is international. Science thrives on open communication. Science is a model for international communication. Indeed, the scientist Sakharov has played a fundamental role in the liberalization of policies within the Soviet Union. His model was communication among scientists.

Now I want to talk about fraud

and deception. Scientists are like children. As individuals, they are easily deceived by hucksters. Because science thrives in an atmosphere of open communication, scientists don't look for secrets, hidden mechanisms, or hidden messages. For example, during the 1970's, many European scientists sought and found significance in "spoon bending" and other tricks by the Israeli psychic Uri Geller. Geller's procedures were debunked by a magician-The Amazing Randi. Scientists themselves were willing to accept what Geller said at face value because they're not used to trick explanations. They can be thrown off by elementary forms of deception.

Scientists do occasionally embellish data or results. They do that with the full understanding that if they are caught, and if they are wrong, their careers are kaput. They know it's wrong, and still they sometimes do it, and it's unforgivable.

Funding patterns in the United States and elsewhere may actually encourage some forms of deception. Big science creates special problems of fraud. But deception and fraud have always been present in science. So. I think it's important for scientists to convey a sense of ethics to students. Research students should learn from the professors what's O.K. and what's not O.K. We teach our students that they should not put their name on a paper or a research report until they're sure that it's correct because it's their name and their reputation that is at stake. They have to defend their work to us and we have to defend our ideas and conclusions to them. Science thrives in this open atmosphere of questioning, with an adversarial relation between the person who is claiming something and the one who seeks justification for the claim.

Ben Stark
Good science could be said to have two components. First is the choice of a problem considered "important," that is, the answers to which are expected to provide particularly useful or fundamental information. Second is the execution of the experiments or theoretical work required to solve the problem. This second component is the one usually associated with poor science, in particular accusations and instances of scientific fraud. It is possible, however, that the first component might also be a source of questionable practices.

Notable recent cases in which execution, or absence of execution, of experimental work has been the source of fraud, have included clear and extreme abuses such as fabrication of data or plagiarism of data already published. Fraud can also take much more subtle forms, such as minor alteration of data. The message to students to counter such behavior is that any alteration of what Mother Nature provides is absolutely prohibited.

Of course, you can be completely ethical and still produce data which are artifactual, too sparse, or too widely scattered to give clear answers to the questions asked. Sometimes experiments are so difficult that such limitations cannot be avoided. There is no ethical problem if these limitations are clearly noted when the data are presented. Whenever possible, however, we should stress to students the importance of trying to overcome these limitations. The necessary practices range from simple ones (repeating experiments a sufficient number of times) to more difficult ones (constantly examining and, if necessary, changing the experimental design so that artifacts can be eliminated and scientific questions answered more directly). An important corollary of these practices is never to presuppose so strongly what the results of an experiment should be that the experimental design or interpretation is even subconsciously skewed against alternative explanations.

Much more difficult is formulating criticisms and recommendations concerning the choice of an area of inquiry to pursue (the first component of good science). As recently as when I was an undergraduate (in the late 60's and early 70'sJ, one of the real advantages of a career in pure science, our professors told us, was that you could work on anything that interested you, no matter how obscure. The rationale was that there was no way to tell beforehand which area of research would prove important later, so all were worthwhile.

That philosophy may still be true in theory, but in the real world of the '90's it is inoperative. The demand for federal support for scientific research has increasingly outstripped the supply. The consequence is fierce competition for grant money from the NSF and NIH. It is now very difficult to get funding for unusual or heretical ideas. The fundable proposals still must have some novel aspects but they cannot be too far from what are considered important mainstream ideas.

While many mainstream ideas are, in fact, fine, this channeling of research can cause scientists, who tend to be parochial anyway, to think in narrow ways. This, in turn, can put great pressure on their students to think the same way. The net result may be to stifle investigation in directions lightly regarded within the mainstream, including those that may ultimately turn out to be important. I have seen a heretical idea put forward by a graduate student and met with an attitude varying from indifference to opposition by his advisor. When his advisor finally accepted the idea and tried to present it to the scientific community, he too met with indifference and opposition. Just a few years later, the idea was hailed as one of the greatest of the last several decades and, ironically, is now part of the mainstream.

What should we teach the students of today about how to do good science? It can be distilled into a few simple axioms: We cannot presuppose the solutions to the mysteries left for us to solve. We cannot presuppose which of these mysteries are the most important to solve. In working towards a solution, we must try to be as objective, honest, and careful as possible. Given pressures today, this may be increasingly difficult, but we have to do it anyway. Mother Nature expects no less.

"A Letter to the Editor"

Charles S. Levy, D.S.W., Flushing, New York

The problems of ethics and risk assessment are effectively reviewed in the January, 1991 issue of *Perspectives on the Professions*. A distinction that can be usefully emphasized is that between values and ethics: between what society values for its constituents in the realms of environmental pollution, global warming, the availability of experimental drugs, etc. and what society and its constituents owe to each other by way of duties and obligations. The responsibility of scientists who measure and assess risks in these realms, and estimate the cost of coping with them, is analogous to that of auditors who owe duties to those who employ them, and also to those who rely on their audits. While they provide data for society's decision-making regarding risks and costs-whatever society may ultimately choose to do-their ethical responsibility to society's constituents requires care lest they be moved to put disproportionate weight on cost in making their recommendations. That is something for society to work out on the basis of its values.

In a book I've just written (tentatively entitled, *Social Work Ethics on the Line*), I've applied this perspective to risk which affects the ethical responsibility of professional practitioners towards clients and others whom their professional practice affects. Risk becomes one of the premises of ethics (general and professional), along with the relative positions of actors in a situation, their relative vulnerabilities, and their relative opportunities.

The issue I pose for ethical judgment and resolution, as well as evaluation, has to do with what participants have to risk or lose in a relationship or encounter, and what they have the opportunity to do about it. 'Whatever of material or intangible value to a person-money, autonomy, access to goods and services, legal rights or representation, physical well-being, emotional stability-whatever the person is at risk of losing to, or being deprived of by, another because of the relationship or transaction, and their relative position in it, becomes a premise of ethics and ethical responsibility when it is in real or potential jeopardy.

Whether it is society, a scientist, or a human service practitioner-or anyone else-that stands between people and their risks to which they are exposed, ethical responsibility is incurred. Included is the responsibility to assess the risks, and to take them into account in making ethical judgments and acting upon them.

This is a bit afield of the focus of your January 1991 issue, but it does relate to professional responsibility and its broader ethical implications. It is also a way of indicating the impact of *Perspectives* in general. Thanks.

"Do the Right Thing: Three Engineers on "Good Engineering""

Harnid Arastoopour
I am an engineer. Engineers are consumers of science. If the science is not good, we start from the wrong foot and everything is going to be disastrous. Let me make clear what I mean, drawing on my own field, chemical engineering.

What is chemical engineering? Chemical engineering is the design, development, and management of the process and facilities that convert raw material into useful products-working hard to get the optimum procedure to make better materials or better products. I will give an example.

What do we do with our waste? The chemist can look at it and say: uh huh, there is carbon, there is hydrogen, and these two can combine together, we can get some hydrocarbons out of it. Great! It's fuel, petroleum, gas. With scrap tires, we can get gas, oil, and carbon-three useful products-that's great!

An engineer will take the idea and try to develop a process that's feasible. We have to worry about heat transfer and fluid dynamics. We have to worry about process control, about the reaction, about the design's economics. The idea may be important scientifically. We really can convert a to b and get a useful product. But if we have to spend more money than we're getting out of it-if, for example, we'll get oil out of this product but at a cost three times more than imported oil-the process is not feasible.

Good engineering is also different from good science because we engineers have to be much more careful in what we do. Chemical engineers are involved with all aspects of the energy, environment, food processing, pharmaceutical and chemical industry. These industries are critical to modern life. Their impact on us is immediate. If we're wrong, we create a lot of problems immediately. So, it is important to be careful and know what is good science and what is good engineering.

How can we provide our students a good engineering background? First, we need knowledgeable faculty and students. It's also important that both of them are committed. Next, we need sufficient financial support. Unfortunately, the percentage of GNP devoted to education and research in the United States is lower than in most European countries. We need laboratories, equipment, and staff. We also need the opportunity for people who are doing the work to update.

Janine Larsen

I am going to limit my talk to how I try to convey what is good engineering to students, mostly undergraduates. Those are the students that I'm trying to reach because they are going to go out and do the hard brunt-work of engineering while the rest of us do our brunt-work research here.

The main thing I try to do during any lecture is ask the question, "Does this make sense?" I never expect students to come up with one line of an equation without looking at it and looking at the results and asking, "Is this a reasonable answer?" If you don't ask that, you miss some of the most obvious problems, such as being off by a factor of ten.

The most important place for looking at results and asking these questions is in a laboratory. For much of your undergraduate education, you know the right answer before you start the experiment. It's easy and tempting when you get the wrong answer because you had the heat on the chemicals too long, to fill in the right answer anyway. Of course, that should never be allowed.

An upper level undergraduate lab in engineering often is the first time you're ever faced with no one right answer. All of a sudden, you have to design and test your design. That's where, for the first time, you're going to say, "How am I going to report this and what happens if I don't get the answer I expected?"

Probably the most important thing to do there is to try to teach students that it's O.K. to report that you didn't get what you expected. That's the only thing you can report. In fact, those are the most interesting lab reports because then I get to listen to how you think through the problem. Where could this have gone wrong? Why wasn't it what I expected? Perhaps, that's where the most exciting results are going to come from.

Our graduates will not only design and test, they will also be asked to project from the results. What does this mean either to a project or to just a specific incident? The ability to take an observation and project into the future its impact on the design, is important.

One example of how important this can be comes from an engineer at Morton Thiokol, an engineer who had tested an O-ring and found that it wasn't going to hold up. Although he did his job and reported what he learned, other people further up tried to suppress that information. The result was a disaster. I try to make my students realize that's the type of responsibility they carry whenever they do engineering.

Hassan Nagib

There is no conflict between good science and good engineering. All good science is good for engineering. It is impossible to find in the history of science an example of good science that has not been good for engineering.

What is surprising is that good engineering can cultivate good science. Today, we're doing better science because of the engineering that goes into microprocessors and many other things.

Good science reveals the secrets of nature. Engineering, on the other hand, is a way of using those secrets to solve problems other than those that nature has already dealt with in its own way. The biggest difficulties for engineering are political and economic. That's why it's important for engineers to study history.

Today, countries like Japan, Korea, and Germany are doing some fabulous engineering-not just good engineering-while in this country, we are just pointing fingers at each other. The political and economical situation is part of the difficulty. Much funding comes from mission-oriented agencies. Some agencies are not supposed to be mission oriented, for example, the National Science Foundation or the health organizations. But today, the issue is how non-mission-oriented can they continue to be under the pressure of an economy that's looking for certain breakthroughs.

Science and engineering develop through empiricism. That's why almost everybody that spoke before me alluded to the falsification of data, fudging and so forth. Often the breakthroughs come from empiricism, from experiment.

Once you have a breakthrough, you need to build on it. This building is the most fruitful part of the process, but it's the most tedious and difficult. That's when the theory and the models are important. What makes good engineering is, as Professor Arastoopour said, solving problems. He talked about chemical engineering. I'll talk about aeronautics.

Good engineering begins with a well-defined problem. I tell my students that's half the job. On the other hand, as a result of recent advances, we have tools in engineering not readily available to science. In engineering, we have things like looking at problems from a system's point of view using computational models to simulate. Simulation is a lot more powerful in engineering. I think that the next century is going to show a remarkable increase in our efficiency.

I'd like to give you some examples of how good engineering can be and how bad engineering can be. If you look at a B-2 Bomber, you will notice a very interesting similarity between it's tail and that of birds.

The flight of animals has been studied for many years. The most interesting results came from a British scientist living in India. He had been sent to India on a long mission he found boring. So, for about fifteen years, he took every opportunity to go up to the mountains, watch the flight of birds, and write down his observations. The book that resulted is the most valuable one for anybody in aerodynamics.

Contrast that with some bad engineering that went on. During World War II, NACA, the predecessor of NASA, wanted to look at the efficiency of bird flight. They bought birds of all kinds, killed them, froze them, put them in a wind tunnel-for example, suspended frozen geese-and measured the forces. They learned very little.

What scares me when a sophomore or junior does not do well on an exam or a set of homework problems is not that he or she is going to get a bad grade. What scares me is that that student may one day be designing the blender that my daughter will use. The first time I used the Cuisinart, I tried to get its blade to spin with the cover off. I couldn't. The designer made it so well that I had to be very creative to make the blade spin with the cover off. That's an example I give my students. I say, "I hope that you're inability to solve this problem does not mean that one day you will fail in the design of a simple blender because that will cost somebody a finger, a hand, or a life:' Ethics looms large for anybody who is trying to turn good science into good engineering.

"The Good, the Bad and the Ugly: A Structural Engineer on Design Solutions"

Sid Guralnick

It's my pleasure to try to sum up my thoughts on the philosophy of engineering and to give some examples of what I believe is good engineering in my own field, structural engineering. The tasks of the structural engineer are to conceive, design, and execute those load resisting constructs needed by a civilized society to enclose or bridge space. I'd like to emphasize the words *conceive* and *design*. They imply imagination, the imagination to conceptualize actual things that are to be constructed or manufactured. This is the essential feature which distinguishes engineering from science. Engineering is not merely applied science. Engineering may utilize the results of science, but engineering design is a separate and wholly distinct intellectual activity.

What are the responsibilities of the structural designer? He or she has to identify technologically feasible options-again, using imagination-to select that one which maximizes safety and durability and minimizes cost-continuing cost as well as construction cost.

So, engineering involves developing options and making decisions. In that respect, it is like the other learned professions. What does the physician do? A physician makes practical decisions; he decides upon a therapy based upon his diagnosis.

Like other professionals, engineers do not operate in a vacuum. Their activities are subject to constraints. Those impinging upon the work of a structural engineer are: function, site, strength, durability, constructability, economy, and aesthetics.

What is good? We're not going to have a Socratic discussion here-what is true? what is beautiful? and what is good? So, I will just give a definition of the word "good:" For the purposes of this talk, "good" will mean a state approaching a preconceived and established condition or quality in terms of form. It presupposes an idea more or less intuitively recognized as such or one that has previously been found to have worked for the protection or for the advantage of people.

I stressed the word "form" because it seems to me that form, at least form in my profession and the artifacts that my profession produces, is something that I can reach this whole audience with. So, we are going to concentrate on form for the remainder of this talk. Form implies: strength or security, clarity of function, solidity or gracefulness, appropriateness or incongruity, tradition or innovation, order or variety, simplicity or complexity. These are some of the attributes of form. Form, therefore, implies aesthetics.

What is an aesthetic object? An aesthetic object is anything with enough vividness and poignancy to make us appreciate it as given. What are the aesthetic choices that have to be made? Here structural engineering overlaps a bit with architecture. Form, proportion, refinement, and balance: these are some of the aesthetic choices, the decisions that both engineers and architects have to make.

To illustrate my ideas about good engineering I shall, very briefly, trace some of the history of one of the basic structural forms important in my profession.

The dome was carried to a high degree of development by the ancient Romans. Even though they did not have access to the modern technology of materials or to the sciences of statics, dynamics, and solid mechanics, Roman engineers were able to construct stupendous domed buildings, many of which still stand and function 2000 years after they were originally built. How were the ancients able to do this? Is there something timeless about engineering with as much meaning today as it had ages ago?

Vitruvius wrote this at the time of Augustus: "In fact, all kinds of men, and not merely architects [who included the engineers of his day], can recognize a good piece of work, but between laymen and the latter there is this difference, that the layman cannot tell what it is to be like without seeing it finished, whereas the architect, as soon as he has formed a conception, and before he begins the work, has a definite idea of the beauty, the convenience and the propriety that will distinguish it."

In other words, the ancient engineer, just as his modern counterpart does, first conceives of the work in great detail, then he meticulously plans it to fulfill its intended function subject to the various constraints of aesthetics and economy, and then, finally, he constructs the work almost exactly as it first appeared to him in his imagination.

Are there some examples from the past of good engineering or of bad engineering that are instructive? Consider the domes covering: the Pantheon in Rome, built by Hadrian; St. Peter's Cathedral in the Vatican, designed by Michelangelo; and the Schott works of Zeiss in Jena, Germany, built in 1923. All three domes are approximately 130 feet in diameter. The Pantheon dome is approximately 3 feet thick and made of light weight "sandwich" concrete. It weighs approximately 3000 tons. St. Peter's dome is almost 10 feet thick and made of brick and stone masonry surrounded by iron chains. It weighs 11,000 tons. The Schott dome is only 2.36 inches thick and made of steel reinforced concrete. It weighs only 347 tons.

In my opinion, good engineering implies the application of state-of-the-art knowledge. Hadrian's engineers (including Hadrian himself who was trained as an architect) used every bit of significant engineering knowledge and observation that had accumulated to the time when the Pantheon was conceived, designed, and built. It is, perhaps, the most remarkable building ever built. It has endured 2000 years during which it has suffered several earthquakes, many fires, and assorted vandalism. Considering the state of knowledge of the ancient Romans, surely everyone will agree that the Pantheon's design is engineering at its best.

Now let us examine St. Peter's dome. It was built in the 16th century by Michelangelo who certainly had every opportunity to study the nearby Pantheon. Yet, to the best of our knowledge, neither he nor his associates made a thorough examination of the Pantheon when designing St. Peter's dome. The dome was designed without having as clear an idea of how such a structure functions as the ancient Romans had. The design was clumsy, enormously wasteful, and not very durable. It has been substantially rebuilt three times during its 400 year life. In short, the dome of St. Peter's Cathedral represents bad engineering, primarily because it did not take advantage of information about dome construction easily obtained from a careful study of the nearby Pantheon. The engineering that went into the design and construction of St. Peters's Dome was not state-of-the-art.

What about the dome over the Schott works at Jena? Was it good or bad engineering? It is, quite obviously, an efficient structure because it weighs so little. It covers the same enormous span as the Pantheon or St. Peters', yet it weighs only one tenth as much as the Pantheon dome and only one thirtieth as much as St. Peter's dome. How did this order of magnitude increase in efficiency come about?

The design of the Schott dome exhibits several features of 20th century engineering that did not exist in earlier times. First, it was based on a detailed understanding of the strengths of its materials. Second, the design proceeded from a clear idea of how a dome bears and distributes the loads applied to it. Third, and last, the Zeiss engineers succeeded in constructing and solving a mathematical model to predict accurately the stresses in such structures. This accomplishment enabled the Zeiss designers to optimize their design by minimizing the weight of the structure. Interestingly, the mathematical model used in the dome design was first formulated by Zeiss's engineers to enable them to design certain optical lenses.

So, good 20th century structural engineering implies: (1) application of state-of-the-art knowledge of the strength of materials and the mechanics of structures, (2) construction and solution of an appropriate mathematical model capable of accurately predicting the stresses generated by the applied loads, and (3) the search for an optimal construct (the "elegant solution") which minimizes materials, construction costs, continuing costs, or all of these. Certainly the design of the Schott dome is an elegant solution which may be regarded as an exemplar of 20th century engineering. It is, therefore., my conclusion that the Schott dome was just as good an engineering job for its day as the Pantheon's dome was for its day.

As a final note, I would like to explain yet another facet of the intellectual and professional activities that we today call engineering. Engineering has long used a systematic approach to the solution of problems that the 19th-century author, John Stuart Mill, called the "method of detail." For example, when the noted 18th-century French engineer, Mariotte, was asked to determine appropriate dimensions for the pipes to be installed at Versailles, he split the problem into several more detailed subsidiary questions: First, how freely will water flow in pipes of various diameters? Second, what is the bursting strength of various pipes when filled with water under pressure? Third, what is the bending strength of various pipes when carrying water over a gap between two supports? The original problem, considered as a whole, seemed impossible to solve. Yet, if the component parts of the problem are well-enough defined, and if each of these parts is attacked and solved in turn, the problem as a whole can be solved.

Galileo also was a practitioner of the method of detail. When asked by the ship builders of Venice whether ships twice as large as those currently under construction could be built, he advocated treating several subsidiary questions of detail before rendering an opinion on the original question. First, he advocated that tests be made of various woods to determine their tensile and compressive strengths. Second, he began an investigation into the basic mechanics of the bending of beams to determine the stresses engendered by external loads. Third, he attempted to correlate the stresses which occur in beams with the tensile and compressive strengths of the woods used in shipbuilding. No modern engineer would have the slightest difficulty in following the reasoning processes of Mariotte and Galileo.

Beyond the initial step of conceptualization of a work, the engineer must be concerned with its "buildability" or "manufacturability". That is, if the engineer's conception is to be realized, it must be capable of being built by real people using real materials and real techniques not substantially beyond the existing state-of-the-art. We at IIT have often heard repeated the words of Mies Van Der Rohe, "God lies in the details." Engineers sometimes make the same point in different words: "Any fool can tighten a nut with a pencil." While anyone can make a pencil sketch of a connection assembly showing the needed bolts and nuts, it takes an engineer's attention to detail to ensure that a worker will actually find the clearances needed to enable him to tighten the real nut properly with his wrench.

"Close Encounters: Science and Engineering"

Question from the audience: There is a sharp contrast... Hassan Nagib said that engineering is close to science. Professor Guralnick said that engineering is not applied science...

Hassan Nagib: There is a broad spectrum of engineers. There is a broad spectrum of scientists. Obviously, when you take a look at scientists you have the very pure or basic scientists and then you have the more applied scientists. In engineering, the extreme away from science is the design or product engineer. Particularly for the edge of development, new innovation, new breakthroughs, it is really the other group of engineers that is closest to science. A design engineer is not different in many ways from an architect. There is almost an artistic element to a design engineer and you can see that particularly in Sid's comments. I've heard this in other talks on engineering. Aerodynamists talk about a good-looking airplane, not necessarily a high performance airplane, just good-looking, aesthetically pleasing. So, it is important to recognize that while science is a way of revealing the secrets of nature, good engineering is a way of taking the secrets of nature and applying them to solve problems. The closeness needs to be there.

Sid Guralnick: Perhaps I should be more precise. By "engineering;' I mean engineering design. Engineering design is not applied science. Engineering design implies a significant set of creative activities. One must first imagine the artifact -be it a building, a pen, an automobile, whatever. The engineer need not know that in a correct interpretation of Newton's Second Law, force is not necessarily mass times acceleration but is always the time derivative of the momentum. It's really not important for the designer who conceives of a new product, process, or system to know that fine point. What is important is that the designer utilize his or her imagination and then take the product of that imagination and render it on paper or in a computer.

Now, having rendered the product of imagination on paper or in a computer, the engineer can use science to predict the behavior of that artifact, process, or system when it is placed in service. That's where science comes in. The engineer uses science, but does not do what a scientist does. The scientist's task is to discover the nature of Nature. The task of the engineer, who is doing engineering design, is not to discover the nature of Nature. His task is, first, to conceive of a product, process, or system and, second, to predict its behavior in service using whatever science he can bring to bear on the problem.

The modern engineer differs from his earlier counterparts. They did not have science to predict the behavior in service of their products, process, or systems, but they still had the task of creating these artifacts. They had to use trial and error instead of science. You may remember from accounts of the construction of the great Gothic cathedrals that when the centering or framework was removed, the roof sometimes collapsed. When this occurred, the cathedral was rebuilt, using a somewhat different roof support system. There was no science available during the Gothic age to enable an accurate prediction of how a massive roof structure would behave under load. That's the real difference between modern engineering, which is a product of the scientific revolution, and engineering of an earlier era.

The task of the engineer remains the same, however, and that's what I'd like to emphasize. There is no difference between the essential task of the Roman or Gothic engineer and the essential task of the modern engineer. The task remains the same-to create works that people must use and that people desire-that society desires and needs. Scientific knowledge is used in engineering to predict the behavior of an artifact without first using it; that is, to avoid the nasty surprise of pulling away the centering to find that a newly constructed (and expensive) roof collapses.

Hamid Arastoopour: In the last five years, even in the last year, science and engineering have been brought much closer together by the computer-the power of processing. Problems that I can solve today, I could not solve last October because the power of processing was not adequate. Super-computers now allow us to discover phenomena that we couldn't believe existed. We are now looking at viscosities, pressures, and temperatures, we go to the molecular activities and try to develop these processes for the multi-phase system - something that no scientist or engineer would have believed a few years ago. It wasn't possible before we got computer data acquisition. Now I can get a thousand data points in seconds. I can see the phenomena. I can make discoveries and use them. I hope that if I talk to you two years from now, I will be able to tell you much more.

"Things Change: Teaching Science and Engineering in Context"

Question from audience: Is there something about the way you teach science and engineering that can promote good science? What are the best ways to promote the kinds of creativity you associate with good science? What are some of the things that work against it?...

Sid Guralnick: The question you've raised is a good one, an important one, and one which, as educators, we must continually ask ourselves, "Are we doing the right things for the next generation?" I don't have any great words to offer here, only a personal viewpoint. It seems to me that some of the most important things to emphasize in engineering education are knowledge of fundamentals and the necessary bases for engineering practice. Let me give you a specific example.

In much of what we teach undergraduates about my field we use what is known as linear theory. We "linearize" mathematical models of reality because that makes them far easier to deal with. Unfortunately, the real world is not linear. The real world is highly non-linear. It wasn't until recently, as Professor Arastoopour has indicated, that we could deal with the multiplicity of non-linearities that really affect that various systems and processes that engineers encounter. We simply couldn't deal with these non-linearities earlier. S0. we had to linearize intrinsically non-linear processes and systems. Some researchers have attained reputations for the linearizations that they made. For example, Professor Donnell (at IIT for many years) was able to demonstrate that a clever linearization could be made in the solution of a certain eighth-order partial differential equation which permits an analysis of stresses in cylindrical shell structures. Thereafter, that approach was called Donnellization. Today, we don't have to make such linearizations because we can treat many problems as they really are. They are non-linear. So, we must, as educators, impress upon our students that sometimes approximations have to be made because of existing limitations in human capability or understanding. We must emphasize that what we know today and what we do today often rests upon approximations to reality. In the future, many of the approximations we are forced to make today, won't have to be made. We will get closer to reality as human knowledge expands.

I believe that we are obligated not only to teach our students to do the best science and engineering of their own day but also continuously and critically to examine their practices -knowing that 100 years hence people may well look back and say that much of what was done before was trivial.

Hamid Arastoopour: This is probably the key question. How can we make the students listen? I always try to connect what I'm teaching to fundamentals. It’s very important to stick to fundamentals… If students can understand the basics, they can apply them later. I also try to tell them the application. For example, if I'm talking about the processes of non-Newtonian flow of polymers, I can point out-here is the polymer. My example is ketchup or mayonnaise. They could see why, when they put the ketchup upside down, the properties are a function of time. I can teach them, what impact this knowledge is going to have on solving the real problems of society. I think that's very important for students.

Porter Johnson: I think that one thing that we can do to encourage people to go into science and engineering is to inspire them by great models. I grew up during the Sputnik era. I was in high school and college during that period. We were certainly inspired to achieve greater knowledge to help mankind as a result of great ideas and projects. It's somewhat disappointing that the ideas and projects of today don't seem so inspirational. There is a failure to get the message across to our society and a failure of segments of our society to emphasize this message.

"Ghostbusters: Engineering an End to Fudged Lab Reports"

Ullica Segerstrale: I have a question I'd like to address to everybody on the panel. It was suggested by Bob Filler and again by Janine Larsen: What should we do about students fudging experiments in laboratories. It's easy to understand that it's not going to pay off, so to say, in the long run, because one has to learn to stand on one's own feet. But in the short run, it might pay off. Lab reports are graded on whether they are correct or not. So, how do we get around that?

Bob Filler: In the report that I cited from R & D this week, one of the people complained, "That's the root of all of our problems, the university. When we did our laboratory work, there were too many experiments. We had just two months. So we worked together. One group of us did a, another group did b, and so on. When we were finished, we traded reports. We just learned whatever they had done, nothing more than that:" The truth of the matter is, it requires a tremendous amount of time, effort, and concentration by professors and honest assistants to teach the virtues of integrity to students. They will have to learn from example.

I'm not here to attack any faculty member. They are honest hardworking people. But, many of the things you pick up in life are picked up much earlier. Whether it is in childhood, in school, in the university. No matter how well you're taught, however, there are some individuals, for reasons of their own, who feel they have to cut corners, fudge, and the like. Let me tell a story.

Twenty-five years ago at Purdue University, a well-known rofessor whom I know had many of students. One student was brilliant. The professor wanted this student to work on a new chemical compound. Nobody had seen anything like it. Soon the

Twenty-five years ago at Purdue University, a well-known professor whom I know had many of students. One student was brilliant. The professor wanted this student to work on a new chemical compound. Nobody had seen anything like it. Soon the student reported, "I produced the compound. It possesses all the properties expected:' They published the results as a Communication in the Journal of the American Chemical Society, the top ranked journal in chemistry. The student graduated and went off to work for Syntex in Mexico City.

Then someone from Italy read the paper and said, "That's baloney. Theoretically, this is all wrong." The professor at Purdue said, "I can't believe that" He assigned a new student to repeat the experiment. The student couldn't reproduce it. The professor assigned a second student to reproduce the experiment. He also failed.

I told you the professor's prize student was brilliant. He was. He had dry-tabbed the whole thing. He figured out in his head what the properties of the material should be, fudged everything through, got his degree, and went off to Mexico: "Yes, I did this, so what? I got my Ph.D., so long:" The professor had to publish a retraction in the journal, red-faced as it was, and at the next Purdue commencement, the student was defrocked, in absentia.

Hassan Nagib: What Bob Filler has told us happens. It is simply a disgrace. It makes me feel almost unclean if it happens in my profession. I think what is clear is that the failure comes from the reward system. For example: You have a material and you want to measure its conductivity at various levels-maybe some kind of a semi-conductor or something like that. Every student in the class is expected to do that experiment for different temperatures and have a graph with 15 points and many pages of notes on them. That is what drives the students-and drives the professors in their own funded programs-some things that are on the edge.

What we have to be creative about is that reward system: For example, if every student in the class only had to do the experiment at one temperature, but each had to get the accuracy to two decimal points instead of one, and had to share the results with the class, each would have to trust every other. Each of them would have to take the 14 other points and put them on the same graph. They wouldn't have to be there until 6:00 p.m., although the class is supposed to end at 4:30 p.m. They would not have to miss dinner in the dorms or something like that. We have to be creative with our reward system. What do you get for what you do-not just finally in the product but in the learning process? I think that is the key. One quality data point is better than fifteen so-so data points.

"For a Few Dollars More: Changing the Funding of Research"

Question from floor: How does our funding system have to be changed in order to encourage a different kind of research that would stimulate creative initiative and not be this mainstream kind of research?

Hamfd Arastoopour: I'm kind of pressured to answer your question because we are heavily involved in research, not only compared to other departments at HT but among the top few chemical engineering departments in the nation. It is not easy at all. It's a very hard way to get money. The main problem is that the total amount of money dedicated to research and development in the sciences and engineering is very small, compared to expectations and developments. A second problem is that whatever system you develop will have several people to review. And always, where there are people involved, there are problems. For example, everybody wants to get big professors from famous universities so they are in the loop and can get better research, better money.

I believe the way to do a little better than this is, first, to increase the amount of money available for basic science and, second, fund some minimum amount of research for all faculty members. Give them a percentage to stand on their feet, so they can start fighting. Provided with that minimum opportunity, they could produce some results and get ahead. The biggest problem is the starting out. Put some money there.

Bob Filler: Would that we were back in 1960 as far as funding is concerned! But remember that before 1961, except for the Office of Naval Research, there was no government funding of research in this country. Then the NSF, the National Science Foundation, not as the congressmen call it, Non-Sufficient Funds, got $4 million. 1t didn't amount to much, but it's built up. Still, we cannot fund basic research exclusively through NSF It's not big enough. There isn't enough money. As Hamid Arastoopour pointed out, we've got to get out of the political soup of Washington.

Would that every state had the luxury of the State of Texas. You may not be aware that there is a Robert A. Welch Foundation in Texas. Virtually, every scientist, who is a professor in any university, public or private in Texas, when he walks in as an assistant professor, is given $20,000 to $50,000 for a year or two to start research. This can be continued. There are many research professors. If only outgoing Governor Thompson would provide the professors in Illinois with sums like that! But of course, that's a public thing. What we need are private sources of money, to get that seed money. Whether its $10,000 or $25,000 per professor (we don't look for $100,000) doesn't matter. But we've got to give professors a chance to start, to demonstrate the principles of the thing. The idea is that you have to be taken out of the government competition there.

"At the Center"

Robert F. Ladenson,
Philosophy, Illinois Institute of Technology

In September of 1990, CSEP Director, Vivian Weil, began a nine month leave of absence to serve at the National Science Foundation as Director of the Program in Ethics and Values Studies in Science, Technology, and Society. Robert Ladenson, Professor of Philosophy at IIT and CSEP Faculty Associate, is currently serving as Acting Director.

Michael Davis, Senior Research Associate at the CSEP, has received a $211,464 grant from the National Science Foundation to develop a model Ethics-Across-the-Curriculum Program. Davis will work with IIT faculty to develop and implement the program over the next four years.

Educators generally agree that professional ethics will not be learned unless it is taught, and that most undergraduate programs in science and engineering are not doing enough to teach professional ethics. The problem has been how to teach professional ethics. Most curricula do not have room for a separate required course in professional ethics.

The best way to get ethics into professional programs seems to be to include it in ordinary technical courses. When scientists or engineers teaching substantive courses in their professional field integrate ethics into their courses, the implicit message is that ethics is an integral part of the profession.

Unfortunately, few professional faculty are trained to teach professional ethics. They are therefore naturally hesitant to try it. IIT's Ethics Across the Curriculum is designed to overcome this hesitancy in three steps.

The first step is to develop and offer a workshop for IIT faculty in how to teach professional ethics in their technical courses. While this 30-hour workshop will include some ethical theory, its primary focus will be on classroom practice. How do you raise an ethical issue? What objectives should you have? What works? What doesn't? About half the workshop will be devoted to preparing, trying out, and evaluating materials for technical classes to be taught in the fall semester. Fifteen faculty will participate in each workshop. The participants will receive a stipend.

The second step will provide institutional support for faculty who include ethics in their technical courses. Such support will include a continuing seminar for workshop participants and other interested faculty. The grant also allows CSEP to expand its library.

The third step will be a pilot redesign of some senior design courses to make them both more realistic and more likely to be ethically instructive. Faculty from two departments will be provided support to work together to develop ethically complex problems requiring cooperation among students in two or more professional fields.

The NSF grant includes funds to make available to the wider professional community updates on the IIT program. In the grant's second year, there will be a day-and-a-half working conference for staff and volunteers in continuing education programs of professional societies. In the grant's fourth year, there will be a week-long version of the workshop for faculty of other universities. Watch for announcements.

"Announcements"

FREE: *Model Policy and Procedures for Dealing with Allegations of Misconduct in Research Within the University* is basically the 12-page policy adopted by Northeastern Illinois University after consultation with CSEP Excellent point from which to start writing your own policy. It includes: references to the relevant Federal rules; a rationale for the policy beyond "the law mandates it"; definition of key terms such as "misconduct"; guiding principles for interpretation; structures for implementation; extensive due process protection; distinct approaches to "inquiry" and "full investigation"; a method for eliminating investigators' conflict of interest; categories of findings beyond "guilty" and "not guilty"; wide range of possible penalties; principles for proportioning penalty to wrongdoing; and an appeal process. Contact: CSEP, IIT, 166 Life Sciences Building, 3101 S. Dearborn St., Chicago, IL 60616-3793 (ph. 312-567-3017).

BOOKS: Guy Oakes, *The Soul of the Salesman* (1990) offers a sociological perspective on the logic of sales and the resulting moral climate. It is based on a case study in the training of life insurance agents. Contact: Humanities Press International, Atlantic Highlands, NJ 07716-1289 (ph, 908-872-1441 or 800-221-38451.

Marcos Garcia de la Huerta, *Critica de la Razon Tecnocratica* (ISBN 956-11- 0242-K). Contact: Editorial Universitaria, Ricardo Matte Perez 0430, Casilla 10220, Santiago, Chile (ph. 2233765, fax 56-2-499455).

PROGRAM: The University of Georgia has begun offering a *Certificate in Environmental Ethics*. The Certificate is awarded to graduate students completing at least thirty hours of graduate work, including an approved research paper in environmental ethics. Contact: Professor Frederick Ferre, 122 Peabody Hall, University of Georgia, Athens, GA 30602 (ph. 404-542-2823)

CONFERENCE: *What If ...We Change to a National Health Program?*, Seventh Utah Conference on Ethics and Health, 17-18 January 1991. Contact: Continuing Medical Education, 1C117, University of Utah School of Medicine, Salt Lake City, UT 84132 (ph. 801-581-8664, fax 801-581-3647).

Where the Law Ends: Professional Ethics in the '90's, Saturday, 2 February 1991, Sheraton Washington Hotel, Washington, DC, all day session in cooperation with American Society of Mechanical Engineers and National Society for Science, Technology, and Society. Contact: Robert Merideth, Conference Manager, NASTS, 122B Willard Building, University Park, PA 16802 (ph. 814-865-9951).

Integrating Business Ethics: Making Ethics a Way of Corporate Life, 24 April 1991, Grand Hyatt Hotel, New York City, will offer an update on corporate ethics programs, discuss ways to deal with internationalization, relation of business ethics to environmental problems, and role of functional areas in corporate ethics programs. Contact: The Conference Board, 845 Third Avenue, New York, NY 10022 (ph. 202-759-0900).

Ethical Issues in Research, Georgetown University, Washington, DC, 29-30 April 1991, will include panels on: Misrepresentation of Data: US and International Perspectives; Role of Authorship; Conflict of Interest; and Scientific Response to External Pressures (Embryos, Fetuses, and Animals). Contact: Fidia Research Foundation, 1640 Wisconsin Avenue, NW, Suite 2, Washington, DC 20007 (ph. 202-337-7185, fax 202-337-7188).

Conference on the Study of Government Ethics, 12-15 June 1991, Park City, Utah, was organized by the Section on Public Administration Research, American Society for Public Administration, and the Ethics in Public Service Network. Contact: H. George Frederickson, Public Administration, University of Kansas, 318 Blake Hall, Lawrence, KS 66045 (ph. 913-864-3527, fax 913-864-5208).

DEATH: Ivan Hill, 83, former advertising executive and television producer who helped to found the Ethics Resource Center, died in Crystal Lake, Ill., 19 September 1990.

EDITOR'S NOTE: This issue of Perspectives turned the camera inward, as is appropriate in a centennial year. The next issue will turn the camera outward again as we do another issue of *Ethics Around the World*.

The Center for the Study of Ethics in the Professions at the Illinois Institute of Technology was established in 1976 for the purpose of promoting education and scholarship relating to ethical and policy issues of the professions.

 Center for the Study of Ethics in the Professions, Illinois Institute of Technology, Chicago, Ill. 60616-3793, Phone: 312-567-3017.