THE FUTURE OF ENGINEERING EDUCATION
I. A VISION FOR A NEW CENTURY

Armando Rugarcia,
Iberoamericana University–Puebla (Mexico)

Richard M. Felder,
North Carolina State University

Donald R. Woods,
McMaster University

James E. Stice,
University of Texas–Austin

INTRODUCTION

When we walk into an arbitrarily chosen engineering classroom in 2000, what do we see? Too often the same thing we would have seen in 1970, or 1940. The professor stands at the front of the room, copying a derivation from his notes onto the board and repeating aloud what he writes. The students sit passively, copying from the board, reading, working on homework from another class, or daydreaming. Once in a while the professor asks a question: the student in the front row who feels compelled to answer almost every question may respond, and the others simply avoid eye contact with the professor until the awkward moment passes. At the end of the class students are assigned several problems that require them to do something similar to what the professor just did or simply to solve the derived formula for some variable from given values of other variables. The next class is the same, and so is the next one, and the one after that.

There are some differences from 30 years ago, of course. The homework assignments require the use of calculators instead of slide rules, or possibly computers used as large calculators. The math is more sophisticated and graphical solution methods are not as likely to come up. The board is green or white or maybe an overhead projector is used. Nevertheless, little evidence of anything that has appeared in articles and conferences on engineering education in the past half-century can be found in most of our classrooms and textbooks.

In recent years, however, there have been signs of change.[1] Engineering professors have increasingly begun to read the education literature and to attend ASEE conferences and teaching workshops, and some have attempted to adopt new approaches in their teaching. A number of factors are responsible for this increased interest in effective teaching in engineering schools. Growing numbers of parents, taxpayers and legislators have read graphic descriptions of the de-emphasis of undergraduate education at major universities[2] and have begun to

raise embarrassing questions with university administrators. Corporations and employers have frequently and publicly complained about the lack of professional awareness and low levels of communication and teamwork skills in engineering graduates[3-6] and about the failure of universities to use sound management principles in their operations.[7,8]

These rumblings have been heard by the U.S. Accreditation Board for Engineering and Technology (ABET), which now proposes to hold engineering schools accountable for the knowledge, skills and professional values engineering students acquire (or fail to acquire) in the course of their education. Starting in 2001, Engineering Criteria 2000 will be implemented as the standard for accreditation. Thereafter, all U.S. engineering departments will have to demonstrate that besides having a firm grasp of science, mathematics and engineering fundamentals, their graduates possess communication, multidisciplinary teamwork, and lifelong learning skills and awareness of social and ethical considerations associated with the engineering profession.[9]

These driving forces and personal convictions about the importance of education in the academic mission have led increasing numbers of university administrators and professors to question the viability of the way engineering has traditionally been taught. Many, however, are unsure of what the alternatives are to the traditional methods, and even those who know about alternatives fear that transforming the way they teach will require a full-time commitment that will leave them with insufficient time to pursue their research.

Our goal in this paper and in the four that follow it is to offer some tools to engineering professors who wish to become better teachers and to university administrators who wish to improve the quality of teaching at their institutions. This paper attempts to define in some detail the challenges currently facing engineering education. The second article will survey teaching methods that have repeatedly been shown to improve learning; the third will elaborate on methods that help students develop critical skills; the fourth will examine effective ways to prepare the professoriate to learn and implement the new methods; and the fifth will propose methods of assessing and evaluating teaching effectiveness and possible modifications in the university incentive and reward structure that will enable the desired changes to occur on a systemic level.

THE TECHNOLOGICAL PERSONALITY OF THE 21st CENTURY

A system of education is closely woven into the fabric of the society within which it operates. Before examining new ways to train engineers, we might do well to anticipate some characteristics of the society within which the engineers we are training will function. We are writing from the perspective of Mexican, American and Canadian cultures, but we feel that the trends can be generalized to a broad range of developed and developing nations.

We see seven features of the coming century that will pose challenges to future engineers.

Information: Proliferating. In 1989, 10,000 volumes were required just to list the titles of all the books that had been published and roughly 6,000 scientific articles were published every day.[10] The number of documents available has since tripled and there is every indication that that rate of growth will be sustained, if not increased. Moreover, the flood of information will wash right up to the engineer's fingertips through the internet, virtual environments, and CD-ROM discs that can each hold up to one million pages of text.

Technological development: Multidisciplinary. In the early part of this century, engineering practice could be classified along disciplinary lines (although not to the extent that university curricula would have had us believe). The body of knowledge that constituted the working arsenal of, say, a chemical engineer, was well-defined, and distinct from that which characterized a mechanical or electrical engineer or a chemist or physicist. The situation now is much more complex: for example, engineers of all types are finding themselves faced with a need to know electronics and/or biochemistry. The key to better technological development lies in cooperation among the previously separate disciplines to attack problems that have no recognizable disciplinary boundaries.

Markets: Globalized. In the future, industries that cannot compete in the international market are unlikely to survive in the domestic market. Succeeding internationally requires cultural and economic understanding no less than technological expertise.

The Environment: Endangered. Producing more in order to earn more will no longer be the sole paradigm of industry. The threats to quality of life resulting from unrestrained environmental depradations and the depletion of nonrenewable resources are sources of growing concern, even within industry. In addition to quality and productivity, industry will require that profitability be achieved within a context of not harming people or their habitat. Increasingly, industries are adopting "The Natural Step" process, TNS, (or an equivalent) to guide their decision-making about the global use of the world's resources.[11,12] The four principles of TNS are:

1. Substances extracted from the earth's crust (such as oil, fossil fuels, metals and other minerals) must not systematically accumulate in the ecosphere. That is, the rate of mining from the earth's crust must not occur at a pace faster than the extracted species can be redeposited and reintegrated into the earth's crust.

2. Substances produced by society must not systematically increase in the ecosphere. That is, synthetic substances must not be produced at a rate faster than they can be broken down and integrated into natural cycles.

3. The physical conditions for productivity and assimilation within the ecosystem cannot be systematically diminished. Forests, wetlands, prime agricultural land, natural plants and animals cannot be systematically destroyed.

4. Since resources are limited, basic human needs must be met with the most resource-efficient methods available. Industrialized nations cannot use the resources to create luxuries while the basic needs of people in underdeveloped nations are not being met.

Social Responsibility: Emerging. Technology is responsible for much of what we value about our society and our way of life, but it must also take responsibility for the threats to public health and depletion of nonrenewable natural resources that now endanger that way of life. The historical thrust of technological development has been to increase consumption and profit; we are falling well short of where we should be in our ability to provide adequate health care, efficient public transportation, affordable housing, and quality education for all citizens. We are not bridging the gap between the technologically advanced societies and those that do not have even the basic means for survival. While the origins of many of these problems may be political rather than technological, it is up to scientists and engineers to participate in the decision-making processes to a greater extent than ever before. We have obligations to inform ourselves and the rest of the population about the potential social consequences of the decisions that are made, to judge whether the implementation of decisions is consistent with the objective of technology to improve our well-being for citizens of the world (as outlined in TNS principle 4) , and to take appropriate action or choose inaction, depending on the outcome of the judgment. Acceptance of this social responsibility by industry and individual engineers is a necessary step for the survival of our society in the next century. A corporate culture consistent with the four principles of TNS, or equivalent, is needed.

Corporate Structures: Participatory. Companies in different societies are moving toward structures that allow for greater participation of individuals in the decision-making process. Quality circles and small-group planning and troubleshooting sessions with joint participation by management, technical, and operational staff are increasingly common. Layers of middle management have been eliminated, with much of the decision-making power being transferred downward to a broader spectrum of the corporate body. Individual employees are acquiring to an increasing extent the right to take part in decisions that relate to their jobs and to assume responsibility for the consequences of those decisions.

Change: Rapid. Changes of a magnitude that not long ago would have taken years now occur on a time scale of months or weeks, as anyone who purchased a computer over one year ago realizes. Curricula that attempt to remain current with industrial practice by continually providing courses in the "new technology" are likely to be ineffective. By the time the need is identified, the courses developed, and the students trained, the new technology has changed. The education that succeeds will be the one that facilitates lifelong learning, equipping students with the skills they will need to adapt to change.

COMPONENTS OF ENGINEERING EDUCATION

What can we say about the individuals needed to function as engineers in the society whose technological characteristics we have just outlined? Their profiles may be conveniently sketched in terms of three components: (1) their *knowledge*—the facts they know and concepts they understand; (2) the *skills* they use in managing and applying their knowledge, such as computation, experimentation, analysis, synthesis/design, evaluation, communication, leadership, and teamwork; (3) the *attitudes* that dictate the goals toward which their skills and knowledge will be directed—personal values, concerns, preferences and biases. Knowledge is the data base of a professional engineer; skills are the tools used to manipulate the knowledge in order to meet a goal dictated or strongly influenced by the attitudes.

In its early years, engineering education did a good job of transmitting knowledge to engineering students, and it might be argued that it facilitated the development of skills and promoted values in ways appropriate for the time. Until about 30 years ago, most engineering professors had either worked in industry or consulted extensively, and the facts and methods that constituted the knowledge base of the engineering curriculum were by and large those that the students would need in their careers. The tasks most engineers were called upon to perform involved mostly routine and repetitive calculations. Engineering students developed and sharpened the requisite skills by working through numerous laboratory exercises and industry-designed case studies and by participating in cooperative industrial work-study programs and practice schools. The primary values of engineering practice at the time were functionality and profit. A good process was one that did what it was supposed to do in as profitable a manner as possible. Both the engineering curriculum and the faculty reinforced these values.

The circumstances facing practicing engineers today are considerably different from those of the past, and the circumstances of the future will be even more different. Significant changes in engineering education will be required if we are to meet the needs of our graduates in preparing them for the challenges of the coming century. Let us consider in somewhat greater detail the knowledge, skills, and values that will be necessary for engineers to deal successfully with the challenges raised in the previous section.

Knowledge

The volume of information that engineers are collectively called upon to know is increasing far more rapidly than the ability of engineering curricula to "cover it." Until the early 1980's, for example, most chemical engineering graduates went to work in the chemical or petroleum industry. Now they are increasingly finding employment in such nontraditional (in engineering) fields as biotechnology, computer engineering, environmental science, health and safety engineering, semiconductor fabrication technology, and business and finance. To be

effective across this broad spectrum of employment possibilities, our graduates should understand concepts in biology, physics, toxicology, fiscal policy and computer and software engineering that are well beyond the range of the traditional chemical engineering curriculum. Many who work in companies that have international markets will also need to be conversant with foreign languages, which have been phased out of both undergraduate and graduate engineering curricula in recent decades. At the same time, the work done by any one engineer tends to occupy a relatively narrow band in the total spectrum of engineering knowledge. Unlike their counterparts of several decades ago, today's engineering students may never be called upon to work with basic elements of the traditional curriculum such as phase equilibria, thermodynamics, separations, reactions and process design.

For these reasons, structuring a four-year or even a five-year engineering curriculum that meets the needs of most engineering students appears to be an increasingly elusive goal. One solution is to abandon the traditional one-size-fits-all curriculum model and instead to institute multiple tracks for different areas of specialization, relegating some traditionally required courses to the elective category.[13] Designing such tracks and keeping them relevant is a challenging task, but it can be and is being done at many institutions.

No matter how many parallel tracks and elective courses are offered, however, it will never be possible to teach engineering students everything they will be required to know when they go to work. A better solution may be to shift our emphasis away from providing training in an ever-increasing number of specialty areas to providing a core set of science and engineering fundamentals,[14] helping students integrate knowledge across courses and disciplines,[15] and equipping them with lifelong learning skills.[16,17] In other words, the focus in engineering education must shift away from the simple presentation of knowledge and toward the integration of knowledge and the development of critical skills needed to make appropriate use of it.

Skills

The skills required to address the challenges to future engineers raised in the first section may be divided into seven categories: (1) independent, interdependent and lifetime learning skills; (2) problem solving, critical thinking, and creative thinking skills; (3) interpersonal and teamwork skills; (4) communication skills; (5) self-assessment skills; (6) integrative and global thinking skills, and (7) change management skills. From another perspective, ABET Engineering Criteria 2000 requires that future graduates of accredited programs should possess (a) an ability to apply knowledge of mathematics, science, and engineering; (b) an ability to design and conduct experiments, as well as analyze and interpret data; (c) an ability to design a system, component, or process to meet desired needs; (d) an ability to function on multidisciplinary teams; (e) an ability to identify, formulate, and solve engineering problems; (f) an understanding of professional and ethical responsibility; (g) an ability to communicate effectively; (h) the broad education necessary to understand the impact of engineering

solutions in a global/societal context; (i) a recognition of the need for and an ability to engage in life-long learning; (j) a knowledge of contemporary issues; (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.[9,18] In the following paragraphs we will suggest the parallels between our proposed classification of skills and the ABET criteria.

Independent learning, interdependent learning, and lifelong learning skills (EC 2000 Criteria a, d, e, and i). Most students enter college as *dependent learners*, relying on their instructors to present, organize, and interpret knowledge. A model has been developed by Perry[19] for the shift many students undergo from being dependent learners to independent learners to interdependent learners. Perry's model includes nine levels, of which levels 2 to 5 characterize most college students.[19–21]

In Perry's model, dependent learners tend to be *dualists* (Level 2). In the dualist picture of the world, every point of view is either right or wrong, all knowledge is known and obtainable from teachers and texts, and the students' tasks are to absorb what they are told and then demonstrate having done so by repeating it back. A significant part of our responsibility as instructors is to move students from the dependent stance to being *independent learners*, who realize that all knowledge is not known and different points of view may come in shades of gray rather than being either black or white, and that their task is to acquire knowledge from a variety of sources and subject it to their own critical evaluation. Students at this level (which roughly corresponds to Level 4 of Perry's model) should be able to identify the pertinent factors and issues that affect a given situation, see the situation from a variety of perspectives, recognize what they need to know to resolve the situation, acquire the pertinent knowledge they do not already possess, and apply their knowledge to achieve a successful resolution. They should further be able to elaborate their knowledge so that future recall and application will be easy. Evidence suggests that some but by no means all students attain this level of development by the time they graduate.[21–23]

But the instructor's job does not end at this point. Students should be helped to go beyond *in*dependent learning to *inter*dependent learning, recognizing that all knowledge and attitudes must be viewed in context; that getting information from a variety of sources is more likely to lead to success than relying on a narrow range of sources and viewpoints, and that the peer group is a powerful learning resource. These attitudes are characteristic of Level 5 on the Perry scale. Students routinely work with peers to identify key resources and to step through the superabundance of available information to identify what is really important, formulate learning objectives and criteria, assess the extent to which they can believe what they read, and learn from and communicate newly-acquired information to others. In working with others, the students learn to recognize their own learning styles,

strengths, and weaknesses, and to take advantage of the synergy that comes from people with a diversity of backgrounds and abilities working together toward a common goal.[24]

When students leave the university and enter the world of work, they can no longer count on teachers, textbooks, and lectures to tell them what they need to know to solve the problems they are called upon to solve. The only resources they have access to are themselves and their colleagues. If we help them to become independent learners, developing and relying on their own reasoning ability rather than accepting information presented by others at face value, and interdependent learners, using the strength of the group to compensate for and overcome their own limitations, we will be equipping them with the lifelong learning skills they will need for success throughout their post-graduate careers.

Problem solving, critical thinking and creativity (EC 2000 Criteria a–c, e, and k). Some authors[25,26] identify critical and creative thinking as core skills that are applied to problem solving, while others[23,27–32] define problem solving as the primary skill with critical and creative thinking as components. Norman[33] questions whether "general" problem solving skills exist without subject context. Be all of that as it may, to be considered effective problem solvers our students should be able to draw upon a wide range of analytical, synthetic, and evaluative thinking tools, problem-solving heuristics, and decision-making approaches. When given a problem to solve, they should be equipped to identify the goal and put it in context; formulate a systematic plan of attack that incorporates a suitable blend of analysis, synthesis, evaluation, and problem-solving heuristics; locate sources of information; identify main ideas, underlying assumptions, and logical fallacies, and evaluate the credibility of the identified sources; create numerous options and classify and prioritize them; make appropriate observations and draw sound inferences from them; formulate and implement appropriate measurable criteria for making judgments; develop cogent arguments in support of the validity or plausibility of a hypothesis or thesis; generate new questions or experiments to resolve uncertainties; and monitor their solution process continuously and revise it if necessary.[22,26,34]

Interpersonal/group/team skills (EC 2000 Criteria d, g, f). The image of the isolated engineer, working in solitary splendor on the design of a bridge or amplifier or distillation column, probably never was realistic. Engineering is by its nature a cooperative enterprise, done by teams of people with different backgrounds, abilities, and responsibilities. The skills associated with successful teamwork—listening, understanding others' viewpoints, leading without dominating, delegating and accepting responsibility, and dealing with the interpersonal conflicts that inevitably arise—may be more vital to the success of a project than technical expertise. Being aware of others' needs and taking them into consideration when making decisions—the essence

of teamwork—is surely a prerequisite to functioning professionally and ethically, regardless of how these terms are interpreted, and is consequently a necessary condition for the fulfillment of EC 2000 Criterion (f).

Communication skills (EC 2000 Criteria d, g, and h). The teamwork necessary to confront the technological and social challenges facing tomorrow's engineers will require communication skills that cross disciplines, cultures, and languages. Engineers will have to communicate clearly and persuasively in both speaking and writing with other engineers and scientists, systems analysts, accountants, and managers with and without technical training, within their company and affiliated with multinational parent, subsidiary, and client companies, with regulatory agency personnel, and with the general public. Like all the other skills mentioned, effective communication is a skill that can be taught, but doing so requires a conscious effort from those who design curricula.

Assessment and self-assessment skills (EC 2000 Criteria d, f, and i). Gibbs[35] suggests that "whoever owns the assessment, owns the learning." The more we can empower students to assess accurately the knowledge and skills of others and their own knowledge and skills accurately, the more effective and confident they will become as learners. Moreover, as professionals all of our graduates will receive performance reviews and many will administer them to others. Developing assessment skills could be an important component of their preparation for professional practice.

Integration of disciplinary knowledge (EC 2000 Criteria a–e and h–k). Chemical engineering students get used to solving problems within the narrow context of individual courses. They solve thermodynamics problems in the thermodynamics course and heat transfer problems in the heat transfer course, often never recognizing that the two subject areas are intimately related. As professionals, on the other hand, chemical engineers rarely solve "thermodynamics problems" or "heat transfer problems." Rather, they solve problems, drawing on knowledge from thermodynamics and heat transfer and economics and safety engineering and environmental science and any other discipline that pertains. Doing this well requires both generic problem solving skills and integrated and structured knowledge of the engineering curriculum.[14,36] Thermodynamics and heat transfer should be seen as related applications of the law of conservation of energy and not as separate, self-contained subjects taught at different times by different instructors using different textbooks.

Managing change (EC 2000 Criteria d, f, h, j, and k). The one certainty about engineering in the coming decades is that it will change, because everything else will change. The growth of technology will lead to rapid product obsolescence and a decreasing need for engineers to perform the tasks that occupied most of them for most of this century, and also to a growth in nontraditional job markets for engineers, especially in the

international arena. Industries that lack the capacity to adapt and change to shifting markets and new technologies will not survive, and successful engineers will be those who can manage change, especially when change is thrust upon them.

Attitudes and Values

Vesilind[37] says that the most lasting effect of education on students is the maturation of their values and ethical sense. Essays on this subject[38–44] suggest that engineers should be inculcated with the values of willingness to participate, concern for the preservation of the environment, coequal commitment to quality and productivity, and involvement in service to others. The fallacious assumption of those who designed the engineering curricula of the past half-century seems to have been that including several humanities courses should be sufficient to produce responsible and ethical engineers. The failure of the engineering curricula to address attitudes and values systematically has had unfortunate consequences. Engineers often make decisions without feeling a need to take into account any of the social, ethical, and moral consequences of those decisions, believing that those considerations are in someone else's purview. By default, the decisions have consequently become the exclusive province of economists and politicians, who lack the ability to predict or evaluate their consequences. The social penalties discussed in the introductory section have been the result of this development. EC 2000 Criteria f (an understanding of professional and ethical responsibility), h (the broad education necessary to understand the impact of engineering solutions in a global/societal context), and j (a knowledge of contemporary issues), and in part, i (a recognition of the need for lifelong learning) arose from a perceived need to correct this situation.

OBSTACLES TO CHANGE

In the traditional approach to teaching, the professor lectures and assigns readings and well-defined convergent single-discipline problems, and the students listen, take notes, and solve problems individually. Alternative pedagogical techniques have repeatedly been shown to be more effective and much more likely to achieve the objectives set forth in the preceding section. Among these techniques are cooperative (team-based) learning, inductive (discovery) learning, the assignment of open-ended questions, multidisciplinary problems and problem formulation exercises, the routine use of in-class problem-solving, brainstorming, and trouble-shooting exercises, and other methods designed to address the spectrum of learning styles to be found among students in every class.[45–47]

The superiority of the alternative methods at achieving desired both cognitive and affective educational outcomes has been demonstrated in thousands of empirical research studies[24, 45–49] and is heavily supported by modern cognitive science.[50] Nevertheless, straight lecturing and convergent problems continue to predominate in

engineering courses at most institutions. A substantial number of engineering professors are still unaware of alternative educational methods, and many who are aware of them choose not to incorporate them into their approach to teaching. There are several likely reasons for this inertia, aside from the inevitable human resistance to change.

Modern universities have, with few exceptions, become totally dependent on research funds to support most of their functions, including educational and administrative functions only marginally related to research. This circumstance has dictated the establishment of research achievement as the primary criterion for advancement up the faculty ladder, and the potential for research achievement as the primary criterion for faculty hiring. In consequence, many young faculty members either have little interest in doing high quality teaching or would like to do it but feel that they cannot afford to invest the necessary time. Individuals in both categories tend to put minimal effort into teaching so that they can concentrate on research, which they view (generally correctly) as the key to their career success. Moreover, most professors begin teaching without so much as five minutes of training on how to do it. Even those who are genuinely concerned about their students and would like to be effective teachers automatically fall back on straight lecturing, which is the only instructional strategy most of them have ever seen.

Another obstacle to change is the fear of loss of control. Lecture classes in which student involvement is essentially limited to passive observation (perhaps broken by occasional questioning) and out-of-class problem solving is safe: the professor is in almost complete control of what happens in class. On the other hand, it is hard to predict what might happen in a student-centered class. Digressions may occur, making it difficult to stay with the syllabus, and the discussion may wander into areas in which the professor is not all that comfortable. Perhaps worst of all, the students may simply not buy into the program, remaining indifferent, uncooperative, or perhaps sullen in their refusal to get involved in the planned activities.[51,52] Like any other skill, directing student-centered classes is an ability that can be learned and improves with practice. Unless some training is provided and feedback given on initial efforts, however, professors courageous enough to try the new teaching methods are likely to become discouraged, give up, and revert to straight lecturing.

In short, no matter how effective they may be, the new approaches to teaching will not automatically replace the old approach. The university administration must take steps to establish a suitable climate for change before any significant change can take place.

FACTORS SUPPORTING CHANGE

As imposing as the obstacles to change may be, we do not believe they are insuperable, and indeed several things are happening that are conducive to change.[1] As noted at the beginning of this paper, legislatures

and industry have been exerting increasing pressure on universities to pay more attention to the quality of their undergraduate teaching programs, and growing competition for a shrinking pool of applicants for engineering school has provided further impetus for change. In the United States the new ABET criteria were developed in response to these stimuli, and the knowledge that in a short time they will be used to evaluate all engineering programs is substantially increasing the pressure to change. Moreover, major support for educational reform has come from the National Science Foundation Division of Undergraduate Education and the NSF-sponsored Engineering Education Coalitions. This support has led to the emergence of a large and rapidly growing number of innovative programs and instructional methods and materials in the past decade, as a perusal of recent issues of the Journal of Engineering Education makes abundantly clear. Finally, since both the National Science Foundation and ABET insist on accountability, both traditional and innovative instruction are being subjected to serious assessment and evaluation. The presence of hard evidence to support claims of improvement in learning should make it easier to disseminate education reforms to the skeptical mainstream engineering professoriate.

THE CRITICAL QUESTIONS

The changes that will move engineering education in the desired directions may be grouped into four categories: (1) revisions in engineering curriculum and course structures; (2) implementation of alternative teaching methods and assessment of their effectiveness; (3) establishment of instructional development programs for faculty members and graduate students; and (4) adoption of measures to raise the status of teaching in society and in institutional hiring, advancement, and reward policies. In the next paragraphs, we will propose questions that should be addressed in each of these categories. The remaining papers in this series will be devoted to suggesting answers.

Engineering Curricula and Courses

- What is the appropriate balance between "fundamentals" and "applications"? Should individual courses stress one of these or the other, or should the two be integrated within courses? Should the flow within a course or curriculum generally proceed from fundamentals to applications (deductive presentation, expository teaching) or from applications to fundamentals (inductive presentation, discovery learning, problem-based learning)?

- What steps can be taken to integrate class material across courses and disciplines, so that engineering students become accustomed to thinking along interdisciplinary lines in their approach to problem-solving? How can "clusters of concepts" be presented systematically throughout the curriculum?

- How should the development of critical skills—those we outlined in this paper, and the overlapping set defined in ABET Engineering Criteria 2000—be facilitated in the curriculum? How much should be done

within core engineering courses and how much should be relegated to specialized courses in such things as communication and ethics?

Teaching Methods

- What forms of in-class activities, homework assignments, laboratory exercises, and testing and grading policies and procedures, have been found most effective at increasing knowledge and critical skills and at promoting and reinforcing positive professional attitudes?

- What is an appropriate balance between teacher-centered and student-centered instruction? Between cooperative and individual learning? Between active experimentation and reflective observation? Between abstract concepts and concrete information? Between routine drill and high-level thinking problems, and between convergent (closed-ended) and divergent (open-ended) problems? How can these balances be achieved in practice?

- How can students be motivated to be self-directed learners? How can they be helped to overcome the resistance many of them feel to approaches that make them take more responsibility for their own learning?

- How might we overcome faculty reluctance to try something new in the classroom.

Instructional Development

- What material should instructional development ("teacher training") programs cover? How much should be generic, and how much should be specific to engineering?

- Should the programs be mandatory or optional for faculty members? For graduate teaching assistants? For all Ph.D. candidates?

- What do instructional development programs cost? How can they be financed?

- How do the different types of programs (seminars, workshops, courses) compare in effectiveness at improving teaching? In cost-effectiveness?

Faculty Hiring, Advancement, and Rewards

- Does the requirement that every engineering professor be a disciplinary researcher to enjoy full departmental citizenship have a logical basis? Does it improve a university's teaching program? Its research program?

- Who will teach engineering practice in the coming years as the number of engineering professors with industrial experience continues to shrink? Who will write undergraduate textbooks? Advise undergraduates?

Teach design? Keep the undergraduate laboratory running and periodically modernize it? Can adjunct professors fill these roles? Should they?

- Who will develop innovative and effective teaching methods in the future, do the research to validate them, and help other faculty members implement them?

- Is it possible to assure that every engineering department has at least a few individuals who can perform the preceding tasks with dedication and skill? Can engineering education survive without such individuals? What incentives, rewards, and policies will be required to hire and keep them on our faculties? Can their presence be maintained without completely overturning the current financial structure of the university, which depends so heavily on research funding?

IF YOU GET ONLY ONE IDEA FROM THIS PAPER

We have described many concerns and trends in this paper. The key idea is that traditional instructional methods will probably not be adequate to equip engineering graduates with the knowledge, skills, and attitudes they will need to meet the demands likely to be placed on them in the coming decades, while alternative methods that have been extensively tested offer good prospects of doing so.

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