THE FUTURE OF ENGINEERING EDUCATION

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Abstract *– Thirteen engineering educators and researchers were each asked to choose a particular aspect of engineering's future to address. Each of the authors has contributed a short piece that has been edited into a discussion of the future as we collectively see it. Topics include the stimulating change, the changing university, teaching, learning, research, outcome assessment and technology as well as a look back at predictions for 2000.*

Index terms – engineering education, technology in education, research issues, learning issues.

LARRY SHUMAN: THE NEXT DECADE – LESSONS FROM 1994

Almost nine years ago I was asked to present a paper on engineering education in the next decade. It is worth reviewing those predictions prior to again examining the future. [1]

What major problems confronted us in January 1994? Jagdish Sheth, the Charles H. Kellstadt Professor of Marketing at Emory University suggested that they be viewed in terms of four major trends that would cause paradigm shifts in higher education:

- The changing economy, which portends slow growth and resultant industrial restructuring for the US while a number of emerging nations will prosper;
- The changing population demographics (i.e., an aging population, increasing number of dual career families, rapidly growing ethnic populations, and a decline in the middle class);
- Technological advances, particularly information technology;
- Intense, global competition. [2]

To these, I added a fifth issue - the engineering pipeline problem, which is closely linked with the changing population demographics.

Changing Economy

Consider the changing economy. In 1994, we were in a period of slow economic growth that, combined with the intense global competition and the end of the cold war, resulted in changes in the nation's priorities. Richard Morrow, then Chairman of the National Academy of Engineering, proposed that certain primary forces affecting engineering education resulted from changing priorities with respect to defense, economic performance and environmental responsibility. Industry had begun to focus on customer satisfaction, market share, quality, product and process improvements, value creation, productivity, time to market, and return on investment. Within US higher education there was a growing consensus that we were at the same place that US industry was a decade earlier - poised for a major restructuring and shake-out. There was clear evidence that US corporations were seeking their engineering talent wherever they can find it throughout the world. [3]

Combine this with very tight, and often shrinking state and Federal government budgets, and attitudes among universities had to change. There were increased calls for improved effectiveness, adoption of total quality and continuous improvement approaches, and business-orientation among academics [4].

In short, the health of the US economy, the health of engineering, and to a large extent engineering education are linked. While engineers can create productivity, US engineering remains highly dependent on the political process and the nation's will to address long-term problems with long-term solutions.

Changing Demographics

The US work force has been aging, a problem common to all industrialized countries. The average age of US, European,

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and Japanese work forces are five to ten years older than in many new competing countries, such as South Korea.

Early '90s demographic projections indicated that half of those retiring from the work force by 2000 would be white males; in contrast over 70% of their replacements would be women, minorities and immigrants. Although progress has been made, we still have far to go in attracting women and minority students to an engineering career.

Technological Advances

The fast-developing technology provides both opportunities and serious challenges to engineering and engineering education. In a technological dominated world the engineer becomes the switching point in modern industry and in society as a whole. Yet, these same technological advancements require that the work force's professional competence and basic education continually be updated. Sheth cautioned that the affordability and versatility of certain new technologies, particularly information technology might rapidly change the way education is delivered, particularly when one considers the time and convenience factors related to traditional forms of education. [2].

Intense Competition

The need to become more competitive in the global marketplace has reshaped US, and, indeed, world industry. International competitors value flexible teams with multi-talented members in place of multiple tiers of management. Industry recognized this and put tremendous emphasis on TQM, CPI, and cycle time reduction, and the elimination of management layers and their staff. Team goals, team contributions, and team rewards began to supersede individual goals and contributions. [5].

Morrow asked us to come to grips with engineering education's global role and implications of that role for advancing our national interest. In 1992, 56,000 foreign engineering students enrolled in US universities; almost 60% at graduate level. The majority of these would remain in US and become productive engineers. The challenge would be to find the ways to remain in the forefront, training new generations of engineers to bring something more to the table than engineers of other nations [3].

This remains a difficult task, according to the NSF, the number of BS engineering degrees awarded in the Asian Region (China, India, Japan, Singapore, South Korea and Taiwan) between 1975 and 1990 increased almost three-fold from 93,000 to 261,000 compared to the US which went from 40,000 to 65,000 graduates for the same period. These differences continued to widen over the past few years. The number of engineering degrees earned in the United States remained nearly stable at the 1991 level for several years, and declined again in 1998. In contrast, trend data available for selected Asian countries show strong growth in degree production in all science and engineering fields. Asian institutions of higher education produced 49% of the 868,340 engineering degrees awarded in 1999; the Europeans countries produced another 31.8% but the US produced only 7% (of which may be an underestimated total). [6]

It was predicted that this intense competition would manifest itself in one other way; i.e., a growing competition among engineering schools for students and sponsored research grants and contracts, and consequently, survival. As US universities, faced with decreasing tuition and public funds and increasing costs went through "strategic planning" exercises, the future of a number of smaller engineering schools and programs might become problematic.

The Engineering (and Science) Pipeline

The engineering pipeline problem is: how do we encourage elementary and secondary school students to view engineering as interesting and fulfilling? More than teaching math and science, it is a matter of tapping into their natural curiosity - helping them understand how things work rather than just telling them.

Over a decade ago, Jack Lohmann (now editor of the *Journal of Engineering Education*) cited an NSF survey, which found that 95% of US adults are scientifically illiterate, even though 40% had taken a college course in chemistry, physics or biology [7]. These "scientifically illiterate" adults reflected the well-documented inadequacies of our public education system: only 35,000 out of one million teachers were trained to teach science; 60% of secondary school math teachers and 40% of science teachers did not have a college degree in the major subject which they teach. Thus it is not surprising that only 7% of high school graduates are prepared for college-level science courses [8].

Lohmann drew two conclusions. First, most of the US population was not being educated to function in the everyday world of the 21st century; a time in which scientifically and technologically literate citizens must make critical decisions affecting the economy, health and global community. Second, only a small, academically elite segment of society was being prepared for careers in technical fields. Without dramatic recruitment and retention efforts, especially in the early grades, this technically eligible segment would become even more exclusive [7].

How bad is the US engineering and science pipeline? Of the 4 million high school sophomores in 1977, 750,000 expressed interest in natural sciences and engineering. However, as seniors, two years later, the interested number was reduced to 590,000. After one year in college, the number declined further to 340,000. Seven years later, in 1984, 206,000 received a BS. Degree. Of this group, 61,000 enrolled in graduate school the following year, with 46,000 earning an MS. in 1986. Of those who continued on, fewer than 10,000 would receive their Ph.D. [7]. Indeed, 20% of the middle and high school teachers hired to teach mathematics in 1993/94 were not certified in that area. [9]. For example, only 17 percent of 12th-grade students scored at the proficient level on the NAEP (National Assessment of Educational Progress) mathematics assessment in 2000. [6]

Engineering Enrollment Trends

Eight years ago there are substantially more than two times the number of MBAs awarded annually compared to MS degrees in engineering, as well as more than the number of baccalaureate degrees in engineers awarded [10]. This situation has not changed. In 1999, engineering represented only 7.0% of all US baccalaureate degrees, compared to 18.4% for China, 19.0% for Taiwan, 19.4% for Japan, 22.1% for South Korea, and 29.5% for France [6].

Table 1: US Engineering Graduates

Category	1977		1987		1998	
	Total	**%**	**Total**	**%**	**Total**	**%**
All	49,677	100	74,423	100	60,870	100
Majority	42,672	85.9	56,491	75.9	40,533	66.6
Women	2,044	4.1	11,404	15.3	11,339	18.6
Af-Am.	1,385	2.8	2,315	3.1	3,018	5.0
Hispanic	1,290	2.6	2,554	3.4	4,125	6.8
Asian	1,211	2.4	5,590	7.5	7,002	11.5
Am. Ind.	135	0.3	210	0.3	253	0.4

As show in Table 1, the proportion of majority BS graduates decreased substantially between 1977 and 1998. Although the number of women graduates has remained constant since 1987, the percentage has increased due to a decrease in the total number of BS degrees awarded, a trend that may have recently reversed. The greatest increase has been in Asian BS degree holders; yet, African-Americans and Hispanics represented only 5.0 and 6.8% of the 1998 graduates.

Goals of Engineering Education

A decade ago, Bodogna, Fromm and Ernst proclaimed that engineering education's primary goals should be to develop, in as individualized a way as possible, in each student:

- Integrative capability (analysis and synthesis are supported with sensitivity to societal need and environmental fragility).
- Analysis capability - critical thinking that underlies problem definition.
- Innovation and synthesis capability;
- Contextual understanding capability - appreciation of the economic, industrial and international environment in which engineering is practiced and the ability to provide societal leadership effectively.

The report: *A Vision for the Future of US. Engineers*, from the "2000 Task Force" of the American Engineering Society suggest that engineering education in the 21st century will consist of:

- Depth and breadth in mathematics, science, design and project synthesis, management skills.
- Interdisciplinary and integrative capability
- Trend toward practice oriented advanced degrees, incorporating teamwork and social consciousness
- Commitment to lifelong education. [12]

A result of these is the new ABET criteria; another legacy is the engineering education coalitions, currently being phased out. Yet, eight years ago there were several curricula reform projects in progress. At a handful of universities such as Drexel, RPI, Rose-Hulmon and Texas A&M, where, for the most part, engineering represents the dominant unit on campus, visionary faculty began to radically changing the first two years through promising experimental programs many with the underlying premise to better, and earlier link engineering education to real world.

What has changed in almost nine years? We are still influenced by Sheth's four major trends, and the engineering pipeline problem remains a concern with enrollments of women possibly having peaked, and African-American enrollments still at a disappointing level. A number of educational experiments have been tried, and, unfortunately, many will not survive. The promise of integrated curricula remains just that – a promise. At too many institutions it was piloted under large outlays of NSF funds, but did not take hold once the funding ended. What will the future hold – please read on!

KARL A. SMITH: THE UNIVERSITY [13]

Yogi Berra is probably quoted as often as anyone concerning the future: "Prediction is difficult, especially about the future." One of my favorite thoughts on prediction is by Fritz Dressler: "Predicting the future is easy. It's trying to figure out what's going on now that's hard."

Those today who foresee the demise, or at least radical transformation, of colleges and universities cite what they believe are unique forces at work that have not existed in the past. Sir John Daniel, Vice-Chancellor of the British Open University has proclaimed "...higher education is in crisis, worldwide. The ingredients of the crisis are access, cost, and flexibility, and they blend differently as you move around the globe" [14]. He notes that in the third world, the rate of population growth will require opening one large campus every week, just to maintain current rates of participation – hardly feasible, even in developed countries. The access difficulty is exacerbated by costs that continue to rise faster than consumer prices and family incomes. In the United States, the cost of sending a child to colleges now approaches 15 per cent of median family income at public universities (up from 9 per cent in the early 80's) and 40 per cent at private universities.

Daniel proposes that an essential ingredient in meeting the cost/access challenge is the appropriate application of new technology to extend educational opportunities beyond the campus. But he points out that in the United States, this will require a change in our dominant educational philosophy from a "teacher-centered" to a "learner-centered" focus.

To most U.S. educators, the term "distance education" today implies extending the traditional classroom model to remote locations via two-way videoconferencing, a form of synchronous learning that broadens access only marginally without reducing cost. Educationally- and cost- effective distance education requires asynchronous learning with at least four characteristics: 1) high-quality multimedia learning materials produced by multi-skilled academic teams; 2) personal academic support (tutoring); 3) well-developed, totally reliable logistics; and 4) a strong research base. Successful development and implementation of such a system requires an enlightened, university-wide technology strategy – not our common academic *laissez faire* approach.

Columbia University Economist Eli Noam emphasizes another powerful driver for change in higher education – the reversal in direction of information flow enabled by low-cost electronic storage and dissemination. "In the past, people came to the information, which was stored at the university. In the future, the information will come to the people, wherever they are." Noam questions the continued viability of our educational model - a community of scholars and their disciples gathered around a library. He suggests that "…the strength of the future physical university lies less in pure information and more in college as a community, less in lecture and more in individual tutorial. . . This requires the active management of priorities and a significant unbundling of the credentialing, teaching, housekeeping, and research functions."

Institutions unable to adapt to these new realities may experience significant decline. Strong competition may be expected from commercial providers of high-quality, technology-enhanced independent study materials, with credentialing through effective certification of specific intellectual skills acquisition. "If these programs are valued by employers and society for the quality of admitted students, the knowledge students gain, and the requirements students must pass to graduate, they will be able to compete with many traditional universities, yet without bearing the substantial overhead of physical institutions." [15]

A search of books of the current and future state of higher education turned up over 20 published in the past three years. To cite four of these:

Dancing with the Devil: Information Technology and the New Competition in Higher Education, Richard N. Katz and Associates [16] is a thoughtful, but alarming call for change in higher education. It was co-published by Jossey-Bass and EDUCAUSE (a consolidation of two major higher education technology organizations, CAUSE and Educom) and was sponsored by Pricewaterhouse Coopers LLP. The six chapters were written by two engineers (who were or are university presidents): James Duderstadt and Gregory Farrington; three principals in the sponsoring organization, Pricewaterhouse Coopers; and two from EDUCAUSE.

An example of the alarm is expressed by Duderstadt:

> Those institutions that can step up to this process of change will thrive. Those that bury their heads in the sand, that rigidly defend the status quo or -- even worse –some idyllic vision of a past that never existed, are a very great risk. Those institutions that are micromanaged, either from within, by faculty politics or governing boards, or from without, by government of public opinion, stand little chance of flourishing during a time of great change [16] . . .It could well be that faculty members of the twenty-first century college or university will find it necessary to set aside their roles as teachers and instead become designers of learning experiences, processes, and environments [17].

Duderstadt closes with a number of trends that he thinks will characterize some part of the education enterprise: A shift from faculty-centered to learner-centered institutions, increased affordability, emphasis on lifelong learning, development of a seamless web, improved asynchronous (anytime, anyplace) learning, more emphasis on interactive and collaborative learning, and greater diversity.

Farrington issued a similar warning in his chapter, "The new technologies and the future of residential undergraduate education":

> Will some institutions be at risk? Yes, particularly those that fail to understand that students will increasingly have alternatives and that the comfortable and monopolistic world that educational institutions have enjoyed for so long is shifting and changing. The market for higher education is large and growing [18].

Farrington reminds us to keep our focus on the moon (and not the pointing finger):

> The overall goal should be to make residential undergraduate education more effective by using computers to do what they do best and freeing faculty to devote more time to students on an individual basis. *The goal should be a more personal education experience, not a dehumanized system of learning by machine. Ultimately it is human interaction, discussion, debate, experimentation, and inspiration that are truly worth four years of time and tuition* ([19] emphasis added).

Closer to home, Richard M. Felder, Armando Rugarcia, James E. Stice, and Donald R. Woods, contributed a series of articles to *Chemical Engineering Education* on "The future of engineering education." The first four parts address a vision for a new century [20], teaching methods that work [21], developing critical skills [22], and learning how to teach [23]. The last two focus assessing teaching effectiveness [24] and making reform happen [25]. The authors provided a wonderful synthesis of the literature on effective practice in engineering education that will help faculty meet the challenges facing us.

Several reports from national commission are calling for change in higher education. One of the most recent of these is the National Research Council's *Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology* [26]. The report was written to encourage the postsecondary SME&T community to reflect on questions related to: (1) Science education for all undergraduates,

(2) Preparation of future K-12 and undergraduate teachers of science, mathematics, and technology, (3) Retention of SME&T majors, (4) Making teaching community property, and (5) Obligations of the disciplines.

It outlines six visions, each of which is a call to action supported with strategies for promoting and implementing it. Three are *Vision 2*: SME&T would become an integral part of the curriculum for all undergraduate students through required introductory courses that engage students in SME&T and their connections for society and the human condition; *Vision 3*: All colleges and universities would continually and systematically evaluate the efficacy of courses in SME&T; and *Vision 5*: All postsecondary institutions would provide the rewards and recognition, resources, tools, and infrastructure necessary to promote innovative and effective undergraduate SME&T teaching and learning.

Kennedy's *Academic Duty* [27] is by far the most interesting and valuable book on the present and future of higher education. It is inspiring, thoughtful, and extraordinarily insightful and provides the best introduction to the academy currently available. Kennedy notes that much of the innovation in teaching has come from young faculty members, which is heartwarming, but it is not without risk to them: "We cannot yet assure young academics that their departments will be as interested in their teaching as in their research. But times are changing. The day may not be far off when teaching performances are routinely reviewed by peers, when senior academic visitors conduct teaching 'master classes' as well as give research seminars, and when candidates are told that teaching is important by department chairs who really mean it [28]."

Kennedy discusses many of the forces that are cited by those forecasting the end of the university - he reminds us that "the commanding feature of this process of redesigning the university will be the reclamation of its central mission. . . Accordingly, its improvement must entail putting students and their needs first [29].

Seely Brown and Duguid's *The Social Life of Information* [30] is the most far-reaching and provocative of the four. They state "To see the future we can build with information technology, we must look beyond mere information to the social context that creates and gives meaning to it."

The authors note that the rise of the information age has brought about a good deal of 'endism,' including the end of the press, television, and mass media; brokers and other intermediaries; firms, bureaucracies, and other organizations; universities; politics; government; cities and regions; and the nation-state [31]. They advocate that over reliance on information leads to "6-D vision." The D in their 6D notion stands for the oft mentioned futurist words: *demassification, decentralization, denationalization, despacialization, disintermediation,* and *disaggregation*.[32].

Their Chapter on "Re-education" responds to many of the pressures for change, raises the concern for the "non-equivalence of equivalent diplomas," and "suggests that learners need three things from an institution of higher education: access to authentic communities of learning, interpretation, exploration, and knowledge creation; resources to help them work with both distal and local communities; and widely accepted representations for learning and work" [33].

The authors intend the book as a catalyst for further conversation rather than a roadmap for the future. On the future of higher education: "Despite predictions about the end of the campus as we know it, we suspect that the university of the digital age may not look very different. It will still require classrooms, labs, libraries and other facilities. Nonetheless, we are sure that organizationally it will be very different [34].

As we contemplate the future of higher education, we think it is best to periodically remind ourselves of the best engineering response concerning the future, attributed to Alan Kay, "The best way to predict the future is to invent it." Why should we bother trying to invent the future? We can think of no better reason than the one expressed by the Lakota leader Sitting Bull, "Let us put our minds together . . . and see what life we can make for our children."

ERIC P. SOULSBY: '*ENGINEERING AS THE NEW LIBERAL ARTS*' OR '*LIBERAL ARTS AS THE NEW ENGINEERING*'?

Throughout the 1990s much was said about the role of engineering in the 21st century and the relationship with programs in liberal arts and sciences. Quite often what was being said was "engineering will be the liberal arts of the 21st century." The meaning of such a statement was to imply that due to ever increasing leaps in technology, higher education should shift toward training in engineering and technology in the next century much like schooling in the "liberal arts" dominated higher education in the 1960s.

In 1980, Stephen White, vice president of the Alfred P. Sloan Foundation, argued for the creation of a "New Liberal Arts" under the belief that in the late twentieth century the tools of technology – computing, quantitative reasoning, applied mathematics – deserved a central place in liberal education. During the ten-year period 1982-92, the Sloan Foundation awarded 23 liberal arts colleges nearly $20 million to advance quantitative reasoning and technological literacy in their curricula. [35]

Several in engineering education applauded the efforts of the "New Liberal Arts Program" since it served to introduce non-engineers to engineering and often encouraged students in the arts and sciences to consider majoring in engineering. Since the 1990s were times of dwindling interest among high school graduates to enter engineering studies, steps taken to increase the awareness of engineering and technology were welcomed for the potential recruitment benefits; perhaps more so than for the educational benefits associated with the curriculum innovation.

Engineering graduate education specialization as a result of advances in technology

Advances in technology, dominated by computers, not only influenced thinking about curricula at the baccalaureate level, but also influenced graduate education specialization. Research interests with narrow focus have crept into many areas of post-baccalaureate study associated engineering education. As a result, much of today's engineering at the cutting edge of technology *requires* advanced education at the Masters and Doctorate level.

Some have argued that today's cutting edge engineering education is post-baccalaureate due to the increasingly higher level of expertise needed. The *Technion Report* [36] of the late 1990s made, among several others, the following recommendations:

- Postpone extensive disciplinary specialization to the graduate level
- Actively encourage the top third of the student body to continue studies immediately for the master's degree

Undergraduate engineering education experiments with specialization

As graduate engineering education has specialized, a trickle down into the undergraduate curriculum occurred as faculty interest in research areas also became teaching areas of emphasis. Many programs in specialized areas such as "biomedical", "environmental", "optical", or "photonics" engineering emerged both as a means to allow faculty to develop a research niche at the same time they contributed to the undergraduate mission of their institution. Specialized or trendy programs were also viewed as a way to entice high school graduates into emerging areas of technology; something perceived as a means to counteract dwindling enrollments at some institutions.

Over specialization causes undergraduate engineering to return to the basics and embraces the arts and sciences

The emphasis on advanced technology being part of post-baccalaureate study once again caused a shift in undergraduate engineering education. Dwindling enrollments, along with tight fiscal climates in the 1990s, caused many programs to embrace 'general engineering' at the undergraduate level. A shift away from specialized areas occurred as engineering programs needed ways to maintain productivity within an environment of dwindling resources. Maintaining graduate and research specialization gave way to consolidation at the undergraduate level; i.e., a return to basics.

At the same time, new accreditation standards mandated multidisciplinary study and engineering design ability in a societal context. Engineering programs began to look at ways of infusing curricula with appropriate general studies, business or management course work, while also striving to bridge discipline boundaries.

The tables are turned: liberal arts as engineering at the baccalaureate level

The "New Engineering" curricula in the 21st century will become more and more steeped in liberal arts. This trend is underway already with programs in areas traditional taught in liberal arts and sciences now reaching into engineering programs for the delivery of their curricula. Areas in liberal arts and sciences are making more and more use of computer-based technology to develop curricular opportunities in areas unheard of a decade ago. Examples include programs in "Bioinformatics", "Geological Systems", "Earth Systems Engineering" and "Information Engineering".

While there have been joint liberal arts/engineering degree programs for quite some time, often resulting in a B.A. in Liberal Arts and Sciences and a B.S. in Engineering, more recently the trend toward liberal studies at the baccalaureate level has shown a greater emphasis on liberal arts. For example, the University of Arizona offers a *Bachelor of Arts in Engineering* allowing students to "plan a course of study that reflects their interests in the arts, humanities, business or social sciences, and applications of engineering methods to these disciplines" [37]. Lafayette College has a similar offering for students "aiming for careers in management, law, architecture, public policy, medicine and many other fields in which their technical background is a recognized asset" [38]. These programs meet the need for liberally educated persons who understand modern technology.

We in engineering education have firmly believed that our graduates must be capable problem solvers in engineering design. What we are now seeing is a need for graduates who have been trained in problem solving but whose area of work lies in the non-engineering non-design world. Baccalaureate programs in engineering must begin to meet the increasing demands for technology literate college graduates who are putting problem-solving skills to use in areas formerly thought to be the domain of liberal studies.

Undergraduate engineering education will continue to broaden its reach into the arts, humanities, business or social sciences as technology changes influence the marketplace. Further specialization in graduate programs and research endeavors will continue to place 'cutting edge' engineering education into the graduate curriculum. Practicing engineers capable of producing state-of-the-art engineering design will need graduate study at the Master's degree level. Undergraduate engineering education will become broader, more steeped in liberal studies, providing graduates with a foundation for advanced study in engineering at the same time as opening doors for engineering problem-solvers trained in technological advances to apply this knowledge to broader societal needs than done previously.

DON EVANS: STIMULATING CHANGE

There are several external pressures for engineering education to improve its preparation of new engineers. But what are some of the most effective drivers of change in academe?

I believe there are four basic ways to stimulate change in engineering

1. No one hires our graduates (or there is a creditable threaten not to);
- Although there are threats of this from time to time, industry has not gotten serious about this as yet—except for off-shore universities, they have no other source for the engineering talent they need.
2. Change the accreditation process;
- We have moved from "seat-time" accreditation to "outcomes-based" accreditation, but so far this is producing only minor changes. However, the required "continuous" improvement cycle and the strong emphasis on assessment should continue to drive change.
3. Throw money at universities to change;
- The research money thrown at us for 50 years by the federal government has created our research culture. But we only have about 10 years of history for federal money flowing into education. Although we often have to look hard to find evidence that education has changed in these 10 years, there are some positive signs.
4. Change the reward structure.
- This is critical, but again there has been a little progress. Faculty largely control promotion and tenure criteria, and most of those "controlling" faculty are a part of the research culture mentioned in 3 above. There are still those who think that a "boot camp-like" environment produces the best engineering graduates. Change will be slow but we are seeing some new thinking.

Much has been learned in the last 20 years about how people learn—and much of that does not align well with our teaching practices. Bringing our practices into alignment with research-based best practices will be a very fruitfull pursuit in future years. A good review of the research on learning can be found in *How People Learn: Brain, Mind, Experience, and School*, edited by Bransford et al., [38]. Gollub and Spital [39] have recently distilled the primary conclusions of this book to the following seven points.

- Learning is facilitated when knowledge is structured around major concepts and principles;
- A learner's prior knowledge is the starting point for effective learning;
- Awareness and self-monitoring of learning ("metacognition") are important for acquiring proficiency;
- Learners' beliefs about their ability to learn affect their success;
- Recognizing and accommodating differences in the ways people learn are essential;
- Learning is shaped by the context in which it occurs;
- Learning can be strengthened through collaboration.

So what might the future of engineering education portend? Here are some of the things that have, for me, become less clouded in my crystal ball:

- The instructor will become less a "talking" head and more of a facilitatore of learning. Student to student collaboration becomes extremely important in this transition of pedagogical styles (Gollub and Spital's last bullet above) This is a difficult shift for faculty, and one that people like Karl Smith have been trying to stimulate for over 15 years. Here at Arizona State, we are finding that it takes at least 3 years for a faculty member to make this transition from teacher-centered instruction to learner-centered instruction. It is clear that a one-size-fits-all faculty development program will not be very effective—different types of training have to be designed to the people at different stages in the change process [40];
- Instruction will be guided by a better understanding of pre-held and instruction-generated misconceptions. The work of Hestenes et al. on the Force Concept Inventory [41] clearly confirm Gollub and Spital's second bullet above. Much work is taking place to develop "concept inventory" assessment instruments that should be very helpful in engineering.
- Labs will not be "cookbookish," but will become projects wherein students will be given a goal, some instrumentation and asked to design the experiment and conduct it;
- Assessment will become more "authentic." This is part of what Gollub and Spital's sixth bullet above is all about;
- Rapidly advancing technology will cause increased tensions between:
    - Student presence in the classroom and telepresence through technology. Why should student physically come to class at, perhaps, an unproductive time, when he/she can just as easily watch a talking head on the World Wide Web—and do it at a time most productive to them;
    - Traditional media (e.g., calculator, overhead projector) and new media (e.g., interactive images, 3D with zoom and rotate). 2D images and linear computations often lead to misconceptions for students. If they can interact with a 3D digital figure or image, or if they can use one of the many "solvers," students can obtain a better understanding of the material.
- Stronger connections will be made between subjects to make learning more contextual (Gollub and Spital's first, fifth and sixth bullets above). Our work in the Foundation has found that the following subjects complement each other when integrated together:
    - English and Engineering;

- o Physics and Mathematics;
- o Engineering and Mathematics;
- o Engineering and Physics;
- o Engineering discipline (and subdiscipline) and other engineering disciplines (and subdisciplines)
  1. It is well known that technology breakthroughs are made by people working at the boundaries of disciplines. Giving students opportunities to experience these boundaries can be vey worthwhile;
  2. Subdiscipline integration unites common themes. The integrated "engineering sciences" of TAMU and RHIT are good examples of this.
- The diversity of the students (ethnic, gender, racial, economic, disabilities) will increase—indeed this diversity must be stimulated. Gullob and Spital's fifth and especially sixth bullets are important here. Students come to the university with different backgrounds and experiences; a meaningful context for one student may not be a meaningful context for another. The outcome from this challenge is that we are all going to have to work harder as faculty to insure that we address the needs of all students.

Richard M. Felder: Two Critical Issues

The role of technology in engineering education delivery

As the ability of technology to provide interactive multimedia instruction continues to improve, the impact on traditional educational institutions and publishers is increasingly hard to foresee, but there can be little doubt that it will be transformative. The rich mixture of expertly presented visual and verbal information, self-tests of knowledge and conceptual understanding, practice in problem-solving methods, and immediate individual feedback instructional technology can provide promotes deep learning far better than traditional lecturing can possibly do.

Even now, when we are still fairly low on the technology learning curve, studies comparing technology-based and traditional course offerings are beginning to appear with regularity and technology looks better all the time. Universities that specialize in distance education are learning how to use multimedia courseware and the Internet effectively and the quality of their offerings is gaining increasing recognition. When students in the near future have a choice between (a) attending passive lectures at fixed locations and times in a campus-based curriculum and (b) completing interactive multimedia tutorials at any convenient place and time in an accredited distance-based curriculum, traditional campuses are likely to become less and less attractive to prospective students. The potential impact on the traditional campuses that fail to meet the challenge is not pleasant to contemplate.

The role of educational scholarship in the faculty reward system

Although the balance is starting to shift, at most institutions the scholarship of discovery (aka frontier research) is still pretty much the only game in town, and faculty members who want to make teaching and learning the focus of their careers are likely to end up as second-class citizens if they manage to make tenure at all. The need to combine the power of instructional technology noted above with the advantages of personal contact with live caring professors will become increasingly clear to traditional universities in the coming decade. Doing so will require faculty members who have the desire to make teaching and learning the focus of their careers and who have the skill to excel at it. Expecting these individuals to do so while also meeting the traditional promotion and tenure requirements for disciplinary research is not realistic. Recognition by deans and department heads that one-size-fits-all may not be the optimal for faculty hiring and promotion policy is an important part of the adjustment mentioned at the end of the preceding paragraph.

Larry G. Richards Using Technology to Improve Learning

Which is more effective? A lecture to 589 students crammed into an auditorium at 9 a.m., or a series of asynchronous video segments available on demand? *When do students learn best?* When they determine the pace and timing of a lesson, or when the professor does? At times and places convenient to the school; or when and where the student is motivated to learn? *How should students learn?* Listening to a teacher repeating what is available in a textbook; or actively engaged in problems, cases or projects that challenge and extend their understanding.

Most of us probably agree that learning is best when it is active, and project based; cooperative learning is beneficial; mastery of the material by all students is a desirable goal; learning should be tailored to the individual; and students should have access to instructional materials when they are prepared and motivated to learn. Information technology can help us achieve these optimal conditions of teaching and learning. *The technological revolution in education is just now about to happen.*

The path to the future is in the past

In the early years of the last century, S. Pressey designed and implemented the first teaching machine. In the 1940s and 50s, B.F. Skinner and Fred Keller demonstrated the effectiveness of the Personalized System of Instruction (PSI). In the 1950s, Pat Suppes showed how computer-based instruction could bring students from different initial levels to mastery in a range of subjects (most notably foreign languages and mathematics). In the 1960s, Don Dulany at Illinois provided televised lectures\demonstrations to over 2000 psychology students each semester. The first round of NSF coalitions, in the early 1980s, developed a large amount of high quality educational materials in a variety of subject areas. Each of the enterprises was very successful in its time. What lessons can we learn from their successes and failures?

What hasn't changed?

Developing quality instructional materials takes time and effort. And there are few incentives or rewards at most universities for faculty to commit this effort. The review, assessment and improvement of such materials requires expertise beyond most engineering educators. Much of the design and implementation of instructional materials may happen outside the traditional universities.

Faculty resist change: At the University of Virginia, we have the best technology for instruction available. Outside my office are three fully equipped computer-based classrooms. Each has full Internet connectivity, an instructor's computer and projection system, and a computer for every student. In addition, we have three other connected classrooms and a videoconferencing facility. These facilities are empty much of the time. When they are in use, it is often for standard lectures. Some faculty believe that the effective way to use this technology is to present their lecture notes in PowerPoint. This allows them to speed through more material in less time (with less understanding by the students). J. B. Jones [42] suggests that the situation at the University of Virginia is not atypical.

What has changed?

We really do know "What works!" We understand learning more profoundly than ever before, and we know how to structure instruction to optimize learning [43].

Computing power is available and cheap. Software makes it relatively easy to develop instructional modules. User interfaces are up to the task. Computers allow display and manipulation of all types of symbol systems (words, numbers, equations, pictures, sounds, gestures, film, and music) so we can represent concepts and procedures in multiple ways to appeal to various learning modes and styles.

The distribution channel (Internet and World Wide Web) is in place: communication, publication and distribution of instruction are no longer problems. (But quality often is.)

Customer expectations: Our students understand and can effectively use information technology; they will force us to adapt our classes to new standards. After all, our students can learn what similar courses are like at other schools (or in other departments at their own school). MIT is putting all their course notes on the Internet; this will establish the standard for university courses at all schools in the future.

ABET's philosophy and accreditation procedures: Since we have to demonstrate that what we are doing accomplishes our educational objectives, we will discover what really works (and what doesn't). The future of learning is on-line [44]. At UVA, we have (broadcast) televised master's level classes since 1983. For many years, we made videotapes available for those students who missed class. We noticed that even students who always attended class regularly used these tapes. They reported that having control over the class enabled them to learn better. Groups of students would watch a tape together; they would stop it periodically and discuss the material; they could repeat segments until they were sure they understood the material. In general, students in these classes seemed to master the material to a higher level than those in traditional classes. Now we provide distance learning for on-grounds students, as well as those off-grounds, using asynchronous video on the Internet. Traditional classes can be effectively delivered in this mode; so can non-traditional ones. This year we offered a highly interactive class on *Creativity and New Product Development* in the distance education mode. Virtual teams involving students from around Virginia and the nation created innovative products and business plans.

An unexpected benefit

The intelligent use of technology can enable us to get by with *fewer functional faculty* members. Despite the frequently repeated claims about the necessary interactions between teaching and research, most active researchers do very little teaching, and most exceptional teachers do very little research. As the active teachers retire, many universities will face a crisis: new young faculty with minimal teaching loads will be unable to handle the courses required for accreditation. We better capture the knowledge and skills of the best teachers before they vanish. Modern information technology will allow us to do so.

CHARLES F. YOKOMOTO: EDUCATING ENGINEERS FOR HIGHER LEVELS OF PERFORMANCE

Unless a program has the luxury of being highly selective in its admissions process, its faculty may come face-to-face with a dilemma if the future of engineering education requires higher and higher levels of learning from its students. The foundation of this dilemma can be best understood through analogy in sports performance. I believe that the field of engineering, like competitive sports, will require graduates to perform at higher and higher levels in order to solve the problems that society will be facing in the future. Common sense tells me that problems become more and more complex as we face engineering problems that take on the added dimensions of world competition, overpopulation, diminishing resources, environmental damage, and the like. While the elite universities may be able to raise the performance bar by becoming more selective in its admissions process, programs such as ours may have this flexibility. We are an urban university with a mission to contribute to the economic well being of our geographical location by providing access to the engineering profession to our constituent population. Thus we, and other programs like us, will have to find ways to improve the teaching/learning process in order to educate students who fit the profiles of our current students in such a way that they will be able to perform at the high levels that may be necessary in the future.

Performance in sports keeps improving as seen by the new records that are being set regularly in events where such records are kept and in our observations of the improvements in physical attributes of athletes. I used to coach volleyball teams when a 6' 4" male athlete was considered to be a tall person. Today, this height is barely average. Athletes are getting taller, faster, and stronger. Coaching has gotten better and better by adding weight training, sports psychology, sports science, equipment improvements, and videotapes of opponents to its traditional training methods. For example, U.S. swimming coaches visited East Germany before the wall came tumbling down to learn about their new training methods and new fabrics that propelled the East German swimmers to become a dominant force.

If the engineering-sports performance analogy holds up, students will have to become better learners, develop a deeper understanding of the basic principles, become better problem solvers, become more innovative and creative, and work more effectively in teams while at the same time becoming more skilled at basic engineering procedures, protocols, and methods. They will have to become better educated in the liberal arts and social sciences as problems become more complex due to the inclusion of social and environmental factors. Engineering educators will have a better understanding of teaching methodologies, how people learn at the cognitive level and the style level, student motivation, the use of technology, and authoring software.

ASEE is fortunate that the ERM Division has been able to take a leadership role in advancing the state-of-the art in the teaching/learning process in engineering.

CYNTHIA ATMAN – RESEARCH TRENDS

I would like to focus on trends with related to the future of research in engineering education, specifically research topics, communities of scholars conducting research, and how research can inform practice. These are my speculations as I look to the future.

Research in Engineering Education. There will be growth in the amount of research conducted on engineering student learning and effective ways to teach engineering students. There will also be an expansion of the research methods used and an increase in the level of rigor with which the research is conducted.

Communities of Scholars Conducting Engineering Education Research. There will be growth in the numbers of engineering faculty who incorporate research in engineering education as part of their academic scholarship. The community conducting research on engineering education issues will expand. Scholars in this community will have expertise in a variety of areas (including the learning sciences, cognitive science, anthropology, education technology, etc.). Some of these scholars will work together in interdisciplinary teams.

Topics of Research in Engineering Education. Research in engineering education will cover a broader range of topics, for example, understanding how students learn engineering content knowledge, engineering design processes, complex systems-level thinking and interdisciplinary problem solving. In addition, research will focus on assessing student learning, understanding the learning experience of diverse populations of engineering students, documenting engineering practice in the workplace, and studying how both faculty and graduate students learn to teach engineering.

Using Research to Inform Practice. The engineering education community needs many different models for effectively using the results of education research to inform practice in engineering classrooms and education software.

Centers Devoted to Engineering Education. There are currently more than ten centers focusing on engineering education in Colleges of Engineering across the United States and Canada. More colleges are planning on starting centers. This trend will continue.

Affecting Policy. There will be an increased need for engineering educators to provide input to affect policy at both the state and national level.

ALISHA A. WALLER: RESEARCH APPLICATIONS, EVALUATIONS, AND DISCOVERIES

The learning process is fascinating and complex, universal and yet uniquely personal. Within engineering education, we have made great strides in the past 30 years in understanding many fundamentals of learning engineering. We have explored the impact of appropriately structured cooperative learning activities, the connections created through integrated curricula, and many other important advances in the teaching and learning of our discipline. However, I believe we have now reached a plateau where very few breakthroughs will occur until we develop further our education research capabilities. Thus far, it has been sufficient to use only quantitative methods with some rigor in the design and implementation of research projects in engineering education. If we are to advance our understanding further, we must expand the methodologies that are applied to gathering and analyzing data, deepen our use of theoretical frameworks, and engage in more rigorous critique of our papers and presentations.

I see three important types of research being conducted within engineering education: classroom application research, evaluation research, and discovery research. Each plays a vital role in advancing our collective understanding of teaching and learning engineering through different goals, perspectives, and methods. Reports of each can be found at ASEE and FIE conferences with various levels of rigor. Also each represents an opportunity for individual and collective learning within the engineering education community.

First, classroom research has as its primary goal the application of new ideas and theories to the practice of engineering education. Currently, this is the most common type of work presented at ASEE and FIE. These presentations often consist of two parts: 1) here is what we did; and 2) here is how the students liked it. The importance of this type of research, which is where we find out what works, when, where, and how, calls for more rigor in the conduct and presentation of classroom research projects. In particular, I suggest:

1. Investigators of these projects give more comprehensive descriptions of the situations before implementation to allow other professors to determine whether their own situation is close enough to warrant transferability.
2. The theories, beliefs, and ideas that led the investigators to believe the innovation would be successful should be articulated in some detail.
3. The details of implementation should be available to other faculty to guide their own implementation.
4. The investigators should seek and report multiple perspectives on the impact of the change because whether the students "liked it" or not is an important but insufficient assessment.

Classroom research is vital to the improved practice of engineering education and thus, should be conducted with as much rigor and thoughtfulness as possible.

Second, evaluation research has as its primary goal the assessment (description of system and process) and evaluation (assigning value to the current state of the system and process) of programs – systematic interventions intended to accomplish a set of goals for a specific population. Program evaluation, as it is often called, does not use the word program to indicate a program of study in the same sense that ABET does. Instead "programs" include programs of study, support programs such as mentoring or women in engineering, co-curricular programs such as solar car design teams, and community building programs such as learning communities. Program evaluation is a well-developed discipline within education and is often combined with institutional research as a concentration for a doctorate in education. The engineering education community needs first to import expertise in this area from colleges of education and then to learn it through apprenticeship. This education discipline not only has explicit theoretical and methodological bases, but also requires tacit knowledge gained through experience and practice.

Common wisdom in this area advises that program developers and implementers should not conduct program evaluation on their own programs; hence the evaluator is always something of an outsider. However, to understand, assess, and evaluate a program, it is also necessary to have experience with the context, participants, and goals of the program. Hence, I see a need for some engineering educators to develop internal expertise in conducting rigorous evaluation research in order to increase the validity of the evaluation process and interpretation of findings. Academic engineering is a unique culture which outsiders may have a hard time understanding and interpreting.

Finally, the third type of research that is important to the further development of engineering education is the scholarship of discovery, that is, research whose goal is the discovery of new knowledge. The National Research Council recently released *Scientific Research in Education* [45]. In it, the Committee on Scientific Principles for Education Research delineates six principles that increase the level of rigor and quality of scientific research in education. I believe the engineering education community should adopt these principles as guidelines for the design and conduct of discovery research in engineering education. They are:

1. Investigate empirically
2. Link research to relevant theory
3. Use methods that permit direct investigation of the question
4. Provide a coherent and explicit chain of reasoning
5. Replicate and generalize across studies Pose significant questions that can be
6. Disclose research to encourage professional scrutiny and critique

Although engineering educators are particularly good at posing significant questions and providing a coherent and explicit chain of reasoning, we are not as proficient in implementing the other principles.

Not being trained in education research, engineering education research often lacks explicit theoretical frameworks. I believe that our research would be stronger if we frame it by articulating three levels of theory. The most general level, "big" or "grand" theory, includes perspectives such as Marxism, meritocracy, and positivism. Mid-range theory includes gender as a socially constructed variable, double consciousness of racial minorities, and the building block theory of learning mathematics. On a more local scale are the specific theories that directly influence the choices of methodology – e.g., Myers Brigg Type Indicator (MBTI) theory, gendered communication theory, and theories of bias toward socially desired responses.

Our application of principle three is limited by our knowledge of a variety of methods. Within engineering education, many researchers use an experimental or quasi-experimental design because it is closely aligned to the "scientific method." In addition, surveys are the most prevalent method of data collection, perhaps because engineers generally are comfortable with the statistical analyses that can be applied. However, this focus on experimental designs and survey methods illustrates a larger concern for prevalence than for depth of understanding. Investigating student experiences via a Likert type survey for example, requires that the researchers "know" in advance what issues and ranges of experiences are possible. By definition of the instrument, students are restricted in their opportunities to describe their experiences; hence we lose depth of understanding to gain more confidence regarding prevalence.

In addition, within engineering education, we miss the opportunity to create strands of research that build upon each other over time through our lack of attention to principles five (replicate and generalize across studies) and six (disclose research to encourage professional scrutiny and critique). There are few lines of research in engineering education that include citation chains where one can trace the development of the theory and application over time. Those chains that do exist (for example, Besterfield-Sacre and her colleagues work on predicting retention) are located within one research group's work [46, 47].

The future of engineering education is unpredictable. Will it be absorbed by industrial training and development programs, rendering undergraduate degrees unnecessary? Will it thrive and adapt to the changing student body and industry demands? We can not know in advance. However, we can increase the likelihood of it thriving by conducting rigorous education research to apply theory, to evaluate programs, and to discover new knowledge.

RONALD L. MILLER – EDUCATION RESEARCH

I briefly summarize my thoughts about the future of engineering education, particularly in terms of education research. Any such predictions are assuredly wrong and probably risky, but I hope that my ideas will at least give some food for thought and discussion among those who are concerned with improving the educational process for our students. My perspective for this discussion is one of a tenured full professor who believes we can improve the design and implementation of ways to help a wide range of students better learn difficult scientific and engineering concepts and better appreciate the impact of their decisions on modern society worldwide.

I believe that the past 20 years or so have seen significant research-based progress towards pedagogical and curricular innovations to improve student learning. Building on these accomplishments, I predict that:

- The focus on learning research will intensify. Research questions about how student learn difficult engineering and science topics will be answered by teams of engineering educators and cognitive scientists focusing on constructivist learning models which rely on student mental models and repair of scientific misconceptions.
- More sophisticated pedagogical models will be developed based on recent advances in cognitive and educational psychology. These models will help guide improve classroom practices that value a wide range of diversity among student learning preferences.
- More educational development will focus on learning and teaching fundamental concepts rather than exclusively algorithmic problem-solving techniques. New tools for identifying and assessing conceptual understanding (including concept inventories for identifying strongly held misconceptions) will be developed. These tools will play a central role in classroom and program assessment activities.

In short, I believe we will continue trying to understand the complex but fascinating field of human learning and how best to apply this knowledge to engineering education

JACK MCGOURTY: OUTCOME ASSESSMENT

Student outcome assessment has become a primary focus for institutions of higher education primarily because industry, government funding sources, and academic accreditation entities have pressured them to incorporate student learning outcomes and sound assessment techniques as a way of measuring the results of educational programs and courses. Borrowing from industry, the concept of continuous improvement is becoming part of the academic vocabulary. The most relevant example of this is the use of program objectives, student learning outcomes, and feedback loops in the Engineering Criteria of the Accreditation Board of Engineering and Technology (ABET). While continuous improvement is a worthy goal, there are several hurdles that must be overcome.

The first challenge is to recognize and deal with the positive and negative consequences of altering the educational status quo. Faculty and administrators must be encouraged to review existing curricula and create new offerings based on specific learning objectives. The recent focus on outcome assessment forces faculty to identify specific learning objectives coupled with specific outcomes. Although, there are several formally structured processes in the literature and in practice that academic institutions can follow to implement continuous assessment and improvement, each process has a broad impact on the institution and cannot be successful unless other parts of the organization are properly aligned.

Most faculty have not been given the tools and resources necessary to create curriculum in this manner. While not inherently difficult, defining specific learning objectives in association with actual, measurable outcomes is not an intuitive undertaking. It requires time, thought, and, at a minimum, basic understanding of curriculum development and assessment theories. Without adequate instructional support for the faculty, this fundamental requirement for true outcome assessment cannot be accomplished. However, there are models that can be followed, such as those provided by Felder and Brent [48] for addressing the new Engineering Criteria. He enumerates several educational activities to be implemented in the classroom that will produce each of the 11 student learning outcomes. By following this model, the instructor writes instructional objectives, creates problems with social and ethical scenarios, grades portfolios of design tasks, forms heterogeneous teams, etc. Each of these activities requires a background in areas beyond traditional engineering and science subject matter.

The second challenge targets the culture and structure of our educational institutions. Comprehensive assessment processes cannot be embedded in our institutional fabric without properly aligned structures, policies, and practices. Concepts such as curriculum coherence and cross-disciplinary collaboration cannot occur until departmental boundaries are torn down or, at least, become more porous. The identification of program objectives and a uniform set of student learning outcomes (although their definitions are quite broad) does provide a common focus both within an institution as well as among universities. This is a good starting point, but there are still barriers to overcome.

Possibly the ultimate challenge is the willingness of students and faculty to change their behavior and habits in the classroom. Until the idea of increased intensive interaction between faculty and student (and other identified constituents) can be embraced, outcome-based education will continue to be the subject of debates among educators. The importance of feedback when focusing on outcome-based learning is critical. In short, outcome-based learning will be ineffective without it. Faculty will need to integrate student performance feedback into the classroom learning environment. This integration will have several implications. Faculty will need to become more involved in working with individual students and student teams to offer timely and valid information regarding their development of specific learning objectives. Because this increased involvement will be time-intensive, it will conflict with the current pre-occupation with content and may cause additional consternation at research universities, especially among untenured faculty. But the benefit is its implicit requirement that faculty communicate and interact with students in a more interpersonal manner, which will have a positive effect on learning.

Fortunately, research spurred, in part, by the National Science Foundation, ASEE, industry and ABET, shows a small, but increasing number of examples of effective assessment processes in academic institutions. One national group of researchers is conducting a series of very promising "triangulation" experiments in which multiple assessment methodologies are being tested to measure specific undergraduate outcomes on defined student cohorts. Through these experiments, educators will better understand the applicability of a number of promising methods including: surveys, concept maps, behavioral analysis, competency measurements, measurements of intellectual development; authentic assessments; multi-source feedback; portfolios and data warehousing. Additionally, the role of technology-mediated assessment is being explored, providing opportunities to support the comprehensive application of outcome assessment both within and across institutions. These activities and others will help academic institutions meet the present challenges so that outcome assessment will become an inherent element in curriculum development.

ELIZABETH ESCHENBACH – A NEW PARADIGM

The rapid pace of knowledge development and technology requires a new paradigm to develop engineering students' teamwork skills.

At FIE 2001 I participated in an envisioning exercise facilitated by Alice Agogino and Sheri Sheppard as part of their efforts with the National Academy of Engineering Committee on Engineering Education's two-year project to envision engineering and engineering education in the future [49] My group visualized independent consultants coming together to form teams for particular projects and then breaking up as those projects were completed. These consultants woulr or would not be in the same location or even the same country when working together. These multi-disciplinary teams would have instant access to information and communication with others perhaps via a wrist computer. The teams would be formed according to the expertise needed for the job, and would include a psychologist to assist with team dynamics and an ethicist to assist with the impacts on society that might come from the project.

This future working style would require that engineering education change so that it becomes easier to learn material on a need to know basis, in order for people to keep abreast of new knowledge in the field. This future working style would require that engineering students be comfortable and able to use the most advanced technology to access information and communicate with others. Lastly, and of most importance to me, this future working style would require that engineering education provide students with much deeper awareness and understanding of teamwork than our current curriculum offers.

The future of engineering must include all possible types of people as engineers. However, our current student and working population of engineers does not match the diversity we see in our country [50], nor our world. (See Karl Smith's contribution to this paper above.) Today, many programs require students to learn about teamwork, including working with those in cross-cultural and/or distance learning situations. Up to this point in time, we have not fully developed a curriculum that helps a student appreciate and understand the differences that culture, gender, ethnicity, race, learning styles, values and ethics bring to the problem solving team. To develop such a curriculum, faculty and students will need to analyze, explore and/or question some of their fundamental assumptions about the nature of engineering, the nature of teamwork and the nature of working with those different than one's self.

There may be many paths to developing such a curriculum. One path would be to use feminist pedagogy to develop this new curriculum. (For an introduction to feminist pedagogy see Mayberry [51]). Feminist pedagogy invites students to not only learn the knowledge base of engineering and science, but to also critically examine the social context and power relations that were and still are a part of the development and use of that knowledge. Thus, engineering students would learn how different people interpret and experience the artifacts developed by engineers. Students would develop a greater understanding of the importance of diversity, so that engineers can design solutions to problems that meet the needs of a more diverse range of people. Students would then be asked to translate this understanding to their teamwork experiences, in hopes that they would be more prepared and willing to work with a more diverse workforce.

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