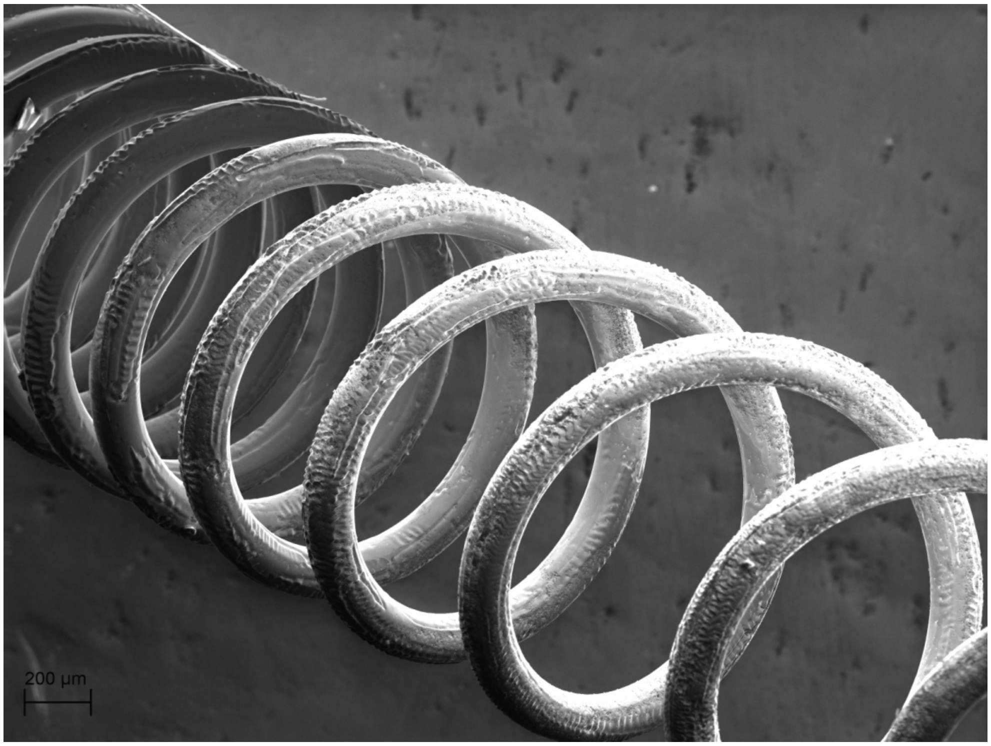
SYMPOSIUM ON ENGINEERING AND LIBERAL EDUCATION



JUNE 4-5, 2010

UNION COLLEGE

SCHENECTADY, NEW YORK

Front Cover: Tungsten Filament

This filament provided an excellent example of damped harmonic motion upon movement of the sample stage. SEM parameters (Zeiss EVO-50): Accelerating voltage: 28 kV; Working distance: 30 mm, Probe current: 480 pA, Magnification: 100 x.

Image acquired by James Chastney.

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Preface

We hope that you find these Proceedings of the third Symposium on Engineering and Liberal Education to be of value. We very pleased with the distinguished group of educators from both engineering and the liberal arts who participated in this forum to continue our conversations about broadening the definition of what it means to be liberally educated. The Symposium explored ways to create a more holistic education for both engineering and liberal arts students based on the conviction that understanding the foundations of technical knowledge can be important for all educated people and that technology need not and should not be taught in isolation. Moreover, we are committed to the idea that innovative solutions to today's complex problems require collaboration that spans the disciplines.

The first Symposium in 2008 drew a small circle of scholars from institutions with similar interests in these objectives. In 2009, with the help of planning partners from other colleges and universities, we broadened the audience to include a more diverse range of institutions and explored the concept of sustainability as a topic of joint interest to engineering and other parts of the liberal arts. The third Symposium, represented by these proceedings, explored the integration of engineering and liberal arts from conceptual, curricular, cultural, and practical points of view with participants from 25 institutions, and with presenters including students and alumni/ae.

Thank you again for your interest in this important topic of integrative education. We hope that you find these Proceedings interesting, informative, and that they will help shape strategic thinking about ways to break down barriers so students and scholars can move more creatively throughout the curriculum and across the disciplines.

2010 Symposium Steering Committee

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Part I: Keynote Addresses

From the Ground Up: Rethinking Engineering Education for the 21st Century

Richard K. Miller
President
Franklin W. Olin College of Engineering

ABSTRACT: The engineering challenges of the 21st century will require leaders capable of addressing the Grand Challenges of our time: global security, health, sustainability, and the joy of living. In addition to solid preparation in traditional STEM[1] subjects, these leaders will need a deep understanding of non-technical issues surrounding technological invention to achieve the desired systems outcomes and avoid unintended consequences. The educational implications require preparing students early in their program for integrative systems thinking across academic disciplines, political boundaries, and time zones. Instead of continuing with the current natural science-centered foundation for a modern engineering education and attempting incremental change, perhaps it is time to start over and redefine engineering as a profession focused on innovation with the deliberate intention to change lives on this large scale. Such a change would require re-thinking the entire paradigm for engineering education.

In 1997, the F.W. Olin Foundation established Olin College for the specific purpose of inventing a new paradigm for engineering education that prepares students to become exemplary engineering innovators who recognize needs, design solutions, and engage in creative enterprises for the good of the world. With an investment of nearly a half billion dollars and ten years of experimentation, the evolving program at Olin College provides one answer to the question: how could you address the educational imperatives of the 21st century within a four-year undergraduate engineering program if you could literally start over—from the ground up? This paper discusses many of the fundamental issues encountered in this re-invention process, as well as some of the results of experimentation.

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[1] Science, technology, engineering, and mathematics

The Shift from Technologies to Solutions. The National Academy of Engineering recently published a list of the greatest engineering achievements of the 20th century[2]. These include such inventions as electrification, the automobile, the airplane, the radio and television, the computer, etc. Each of these inventions resulted in a large scale innovation that changed the way we live. A primary characteristic of such a major innovation is that people are largely unable to remember what life was like before the innovation took place. There is no doubt that the technological innovations of the 20th century changed lives on a global scale and produced enormous benefit for many millions of people. For example, the innovation of widely available clean drinking water in the U.S. is often regarded as a primary cause of the increase in life span of more than 30 years between 1900 and 2000[3].

There is a sense in which technology serves as a kind of amplifier of human behavior. In each successive generation, a smaller and smaller number of people is enabled to affect the lives of larger and larger numbers of other people through the application of technology. The effects may be intentional or unintentional, and they may be beneficial or they may not. The relentless development of new technology raises the stakes on social, economic, and political consequences in each generation.

As a result, these same technological innovations—which are the proud legacy of engineering—are also responsible for a many unintended consequences. In most cases the negative effects of these consequences are relatively small in comparison to the net benefit provided by the innovation, but when the innovation is applied on a very large scale even these relatively small negative effects can become substantial, and they do not affect all people in an equal manner. For example, the introduction of the automobile together with plentiful supplies of petroleum has contributed to the problem of a build-up of carbon in the atmosphere. Also, as mechanized agriculture has lowered the cost of food production and helped prevent massive famine in developing countries (due to rapidly growing population in those countries), it has also contributed to growing levels of obesity among those living in poverty in the U.S.[4] Furthermore, the introduction of the Internet has provided transformational improvements in the ability to communicate across the globe with astounding convenience and low cost (the desired effect), but the resulting overwhelming choice of convenient sources of information has resulted in patterns of behavior where people often simply watch and listen to ideas and commentators with whom they already agree (an unintended consequence). These and many other unintended consequences—largely related to the collective human <u>response</u> to technological inventions—must be better anticipated and incorporated into the solutions to the Grand Challenges of the 21st century if we

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[2] Constable, G., and Somerville, B. (2003) *<u>A Century of Innovation: Twenty Engineering Achievements That Transformed Our Lives</u>*, Washington, DC: Joseph Henry Press (an imprint of the National Academy Press).

[3] Because a relatively high proportion of the deaths in 1900 were the result of water-born infectious diseases.

[4] Since the enormous increase in farming efficiency in the U.S. has produced extremely low costs per calorie of food produced, which contributed to the wide availability of low cost fast foods in poverty-ridden areas.

are to obtain desired outcomes across the globe. This raises an interesting question: whose responsibility is it to "engineer" these large scale human responses to technological advances?

The role of the engineer we envision is that of "systems architect"[5] of complex technical, social, economic, and political systems capable of addressing the global challenges we now face. Such engineers must be creative in conceiving, implementing, and managing the technologies that will shape our future. They must not only be applied scientists who are capable of predicting, creating, and developing the new science and technologies, but also organizational leaders and project managers capable of explaining complex socio-technical issues directly to the public, establishing trust through effective leadership, planning and implementation of integrated projects that deliver desired outcomes—not just products or devices—and do this on time and on budget. In short, they must be engineering innovators who produce innovations capable of transforming the way people live on the planet in ways that result in coherent and coordinated human behavior to address sustainability, health, security, and the joy of living.

Educational Imperatives of the Grand Challenges. The educational implications of producing such engineers are substantial. Not only must these engineers continue to possess exceptional proficiency in STEM subjects, but they must also have substantial new abilities. In particular, they must have a broad awareness of complex global issues, a passion or strong motivation to make a positive difference in the world in the largest sense, and a "can-do" attitude that is characteristic of the best "social entrepreneurs" and political or organizational leaders. These new attitudes, behaviors, and motivations are essential to the preparation of the engineers needed for the Grand Challenges.

The foundation for a broad and integrated education is awareness and interest in complex problems and the ability to communicate with experts across many disciplines. Without this foundation it is difficult to see how the broad education needed can be achieved. However, a cursory review of the structure of our current higher education system reveals that we may have created unnecessary obstacles to this communication through our efforts to provide specialization. It is imperative that we address these barriers to communication across disciplines as a first step toward providing a more integrated education for engineers.

For example, most children in the U.S. attend elementary and high school in public schools where the curriculum is relatively integrated across the full spectrum of academic disciplines. That is, specialization is limited and a high school diploma in the U.S. generally requires some proficiency in mathematics, natural science, social science, literature, the arts, etc. However, when students graduate from high school and go off to college, they are encouraged to select a specific discipline to major in, such as engineering or science, business or economics, English, history, psychology, sociology, political science, art, etc.

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[5] Rechtin, E. (1990) *Systems Architecting: Creating & Building Complex Systems*, NJ: Prentice Hall; and Rechtin, E. (1999) *Systems Architecting of Organizations: Why Eagles Can't Swim*, CRC Press.

Students who choose to major in engineering and pursue an ABET[6] accredited program can expect to spend at least four years immersed in studies that are heavily dominated by STEM subjects. In fact, most ABET accredited engineering programs require that about 75% of the total credit hours for the B.S. degree be devoted to STEM subjects. As a result, it is not uncommon for engineering undergraduates to spend almost all of their time within the "engineering quad" on campus, surrounded by other engineering students. Three-fourths of all the faculty members they encounter and are influenced by are professors of STEM subjects. After four years of this immersion in the STEM culture, engineering graduates naturally acquire a certain bias in looking at the world.

One way of thinking about this general trend is that engineering students are immersed in a four-year study of the world through the lens of "***feasibility***." That is, the majority of their time is spent thinking and worrying about the feasibility of devices, systems, or processes—the extent to which such things are possible according to our current understanding of the laws of nature. Furthermore, they develop a specialized jargon for communicating with each other based on this view of the world, and the majority of their academic role models are engineering or science professors who are experts in assessing this aspect of human activity. When they graduate, there is a sense in which they have been (unintentionally) indoctrinated to view feasibility as the most important of all human concerns, and sometimes to view with skepticism (or worse) other disciplinary views of the world about which they have much less understanding.

On the other hand, if a high school graduate should choose to major in business instead of engineering, a similar immersion develops in the study of the "***viability***" of human activity. If he or she pursues an AACSB[7] accredited bachelors degree in business, then approximately one half of his or her total credit hours are spent studying economics, accounting, organizational behavior, management, and other subjects intended to prepare them for a career in the business world in which the focus is on whether an activity is capable of generating and sustaining financial resources. The lens here is that of the flow of finances and resources over time and the development of sustainable business activity. They often spend the majority of their time on campus confined to the "business quad" surrounded by other students and faculty members with similar interests and bias. They also develop a specialized jargon for communicating with each other based on this view of the world, and the majority of their academic role models are business or economics professors. As a result, they often leave college with a sense that viability is the most important of all human concerns.

Finally, if a high school graduate chooses instead to major in English literature, history, or art, for example, then he or she spends four years studying subjects that are often more widely varied and seldom focused on either

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[6] ABET (formerly the Accreditation Board for Engineering and Technology) is the national accrediting agency for academic programs in many types of engineering and in computer science.

[7] The AACSB (Association for the Advancement of Collegiate Schools of Business) serves as the national accrediting agency for all academic programs in business.

feasibility or viability[8]. Instead, the primary focus of their study is often forms of creative and/or emotional human behavior. Understanding in non-quantitative terms the personal human interaction with the world is critically important, involving human motivations such as love, beauty, feeling, justice, and spiritual meaning. This focus is more often the subject of study in these liberal arts disciplines. Some fraction of the students in the liberal arts is concerned with "***desirability***," or what motivates and satisfies people in a range of circumstances. Their jargon and academic role models here are often chosen from these disciplines, resulting in the perception that this dimension is most important when assessing human activity, often with unintended skepticism toward other disciplinary views with which they are much less familiar.

As a result, our educational system may unintentionally help create barriers to communication across disciplines, contributing to the perception that problems arrive with "labels" on them, announcing that they are either engineering problems, business problems, or more general motivational or societal problems. Of course, these labels are artificial, largely the result of our organizational structure in higher education. The result is an educational system which produces significant barriers to student awareness, interest in, and ability to address complex problems that require multidisciplinary approaches.

Innovation = Feasibility + Viability + Desirability. To fully appreciate the importance of these artificial barriers to communication and understanding, it is instructive to review some recent scholarship in the field of innovation. (After all, our ultimate goal is to produce engineering innovators.) When viewed analytically, large sustainable innovations—the kind that changes the world so profoundly that most people can't remember what the world was like before they were established—all have one thing in common. They all involve the simultaneous achievement of feasibility, viability, and desirability[9]. In this sense, innovation may be viewed as the intersection of the universe of things that are feasible, with those that are also viable, and with those that are simultaneously socially desirable. A Venn diagram is a natural way to envision this.

Without this insight, it is natural for engineers to imagine that innovation is just another name for the next new science or technology. But the majority of technologies or scientific discoveries are either not financially viable or are undesirable in the social marketplace. Only those technological systems that happen to also be viable and desirable have a real chance of becoming a sustainable major innovation. The other technological inventions eventually reveal

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[8] Regrettably, in the past few decades the general education requirements in many fine universities and liberal arts institutions seem to have been relaxed in the area of mathematics and natural science to the extent that these requirements may now often be satisfied either by Advanced Placement credit from high school or by subjects in college that are specifically aimed at non-majors in these fields. Furthermore, few liberal arts programs require significant exposure to the fields of engineering or business. As a result, the gap in understanding in these subjects between engineering or natural science majors and those in more general fields continues to widen, resulting in many unintended consequences such as barriers in communication and cooperation.

[9] Weiss, L., *Developing Tangible Strategies*, Design Management Journal, Vol. 13, No. 1, pp. 33-38, Winter 2002.

themselves to be "just in case" ideas that may someday become stepping stones to other useful ideas, but often do not. The universe of all things that are feasible contains many, many more things that will not result in innovations than those that will[10].

Similarly, the universe of all things that are viable also contains many more things that are not feasible (cold fusion comes to mind) than those that are, and of course, the same is true for the universe of all things that are desirable (a cure for cancer comes to mind).

For the next generation of engineers to truly master the art and science of innovation, they must understand the fundamental importance of both viability and desirability, and they must develop a proficiency in addressing such needs in each project from the beginning. Perhaps the most practical approach is to learn to work together in teams with students from the other disciplines right from the start. If we wait until after they have completed a traditional four-year STEM-intensive education, it may well be too late. The results of our unintended indoctrination will have taken hold, like the hardening of wet cement around their feet. However, by intervening early and facilitating conversations across disciplines in each year of the academic program with both faculty and students who represent the world views of viability and desirability, we may substantially improve our ability to produce graduates who escape the perception that feasibility alone is the most important lens through which to view human activity. Deliberately creating an educational environment that includes regular exercises focused on complex issues with respected experts that represent different disciplines and points of view—in effect, deliberate intellectual collisions in the classroom—may be the most effective way to promote awareness, communication, understanding, and motivation for producing large scale innovations.

Multiple Intelligences and Creativity. Engineering is inherently a creative enterprise. While scientists ask "why?" engineers must ask "why not?" Engineers are responsible for imagining what has never been and then doing whatever it takes to bring these visions to reality. In this fundamental sense, "*to engineer*" is "*to make*."[11]

Furthermore, the uncertainty about the future seems to be as great or greater today than it has ever been, in spite of the rapid growth of advanced knowledge. No one is able to predict what the future will hold in five years, not to mention in 50 years. For example, in spite of enormous professional attention on global financial affairs in many nations and in both government and private enterprise, no one was able to predict and avoid the global financial crisis of 2008-09 which took the world's many experts largely by surprise. Yet, we in higher education are responsible for preparing our students to successfully manage the challenges of the future. As a result, a good case could be made that creativity and adaptability are perhaps at least as important as knowledge in managing uncertainty, and our educational approach

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[10] It is important to note that the observations on which things are feasible, viable, and desirable at any instant are prone to change over time, as new developments arise in these independent realms.

[11] It is interesting to note that the word "engineer" may be used either as a verb or as a noun, while the word "science" always refers to a noun.

should reflect this through deliberate preparation of graduates in this important area[12].

However, it is surprising how little emphasis is placed on creativity within the standard engineering curriculum today. A cursory review of the titles of courses taught and required within most traditional engineering schools shows that a very small proportion include the word "design" and even fewer address creativity[13] in a deliberate way. Furthermore, many of the engineering design courses include very little discussion of creativity and the thought processes that underlie it. This is remarkable given the importance of creativity to the fundamental purpose of engineering.

Of course, engineering is not the only human endeavor with a responsibility for creativity and design. For example, art, architecture, music, creative writing, drama, cinematography, and other visual and performing arts require participants to begin with a blank sheet, imagine what has never been and then bring this vision to reality in ways that touch people's lives. Schools of design also specialize in preparing graduates to take on this role within certain domains.

A study of the methods used in these more artistic fields is instructive with regard to recognizing and cultivating creativity and inventiveness. To begin with, research in the cognitive sciences provides important insight in this area. The pioneering work of Howard Gardner led to the concept of "multiple intelligences."[14] His work and that of others that followed[15] lead to the conclusion by many that all humans have largely independent capacities for learning and achievement (intelligence) in many different areas, including, of course, linguistic and mathematical intelligence which is the central focus of most of higher education today, emphasizing symbolic representations of the world in words and numbers and manipulation of these symbols through the discipline of logic. However, all people also have independent creative intelligences manifest in such areas as visual/spatial reasoning (visual artists), music, and bodily/kinesthetic ability (as for example demonstrated by dancers, or professional athletes, or neurosurgeons). Finally, all people also have varying degrees of innate ability in interpersonal and intrapersonal intelligence, which is apparent in fields requiring teamwork, leadership, persuasion, and management.

It is important to note that except for the intelligences that involve symbolic representation and logic, ***experiential learning*** is fundamental to the learning pedagogy in the creative domain. Musicians cannot learn to

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[12] Robinson, K. (2001) Out of our Minds: Learning To Be Creative, Capstone Publishing (a Wiley Co.).

[13] For the purpose of this discussion, it may be helpful to provide a definition of the terms creativity, inventiveness, and innovation: Creativity is the process of developing original ideas and insights. Inventiveness is the process of developing original ideas and insights that have value. Innovation is the process of developing original ideas and insights that have value, and then implementing them in ways that sustainably change the way many people live.

[14] Gardner, H. (1983; 1993) Frames of Mind: The Theory of Multiple Intelligences, NY: Basic Books.

[15] For example, Sternberg, R. (1984) Beyond IQ: A Triarchic Theory of Human of Intelligence, Cambridge University Press; Kaufman, J. C. and Sternberg, R. J. (2010) The Cambridge Handbook of Creativity, Cambridge University Press; Sternberg, R. J., Grigorenko, E. and Singer, J. L. (2004) Creativity: From Potential to Realization, American Psychological Association.

perform music without spending a great deal of time actually making music through practice and performance[16]. Dancers cannot develop expertise by simply reading about and critiquing the work of others. Similarly, neurosurgeons do not become skilled through reading alone. They must learn through many hours of personal experience. Even poets learn that all important insights in life do not come from reading the work of others, but rather they often require intense introspection. To develop high proficiency in creative fields requires intense personal engagement, focused practice, and introspection[17]. Therefore, it is natural to expect that the production of engineering innovators would benefit from greater emphasis on experiential learning and creative design than exists in the current engineering curriculum.

Furthermore, an increased emphasis on experiential learning would likely provide other important benefits. For example, experiential learning—by its very nature—demands a high level of student engagement. It is not possible to learn passively when involved in experiential learning. Research in education[18] shows that students who are more engaged in their undergraduate studies are more likely to complete their program, to graduate, and to retain the knowledge gained in later years. The pedagogies of engagement therefore offer a number of important benefits in rethinking the educational process for engineers.

Olin College and the Effort to Create a New Paradigm for Undergraduate Engineering Education. In 1997, the F.W. Olin Foundation of New York announced its decision to end its decades-old grants program[19] that funded academic buildings on private university campuses and devote the remainder of its considerable resources to the establishment of an entirely new and independent residential college devoted to the undergraduate education of engineers[20]. The specific intent of the Foundation in establishing the College was to create a new paradigm for undergraduate

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[16] Levitan, D. J. (2007) This Is Your Brain on Music: The Science of a Human Obsession, Plume/Penguin Books.

[17] A particularly vivid explanation of the role of experiential learning in developing expertise in these non-analytical areas is provided in the recent book by Daniel Coyle, (2009) The Talent Code: Greatness Isn't Born. It's Grown. Here's How. Bantam Books. In addition, recent research in brain plasticity provides important insights in the way experiential learning actually "re-wires" the brain and leads to more holistic understanding and ability, as explained in the recent book by Norman Doidge, M.D.(2007), The Brain that Changes Itself: Stories of Personal Triumph From the Frontiers of Brain Science, Penguin Books.

[18] Kuh, G. D. (2009). The National Survey of Student Engagement: Conceptual and empirical foundations, in R. Gonyea and G. Kuh (Eds), *Using student engagement data in institutional research*, *New Directions for Institutional Research*, No. 141, San Francisco: Jossey Bass; Astin, A.W. (1984). Student involvement: A developmental theory for higher education, *Journal of College Student Development*, 25(4), 297-308.; Kuh, G.D. (2001). Assessing what really matters to student learning: Inside the National Survey of Student Engagement. *Change*, 33(3), 10-17,66.; Kuh, G.D., Cruce, T.M., Shoup, R., Kinzie, J., & Gonyea, R.M. (2008). Unmasking the effects of student engagement on college grades and persistence. *Journal of Higher Education*, 79, 540-563.

[19] Over a period of approximately 50 years, the Foundation donated all the funds for the construction and furnishing of 78 buildings on 58 college and university campuses across the U.S. Recently, the F.W. Olin Foundation was dissolved, after transferring all of its remaining funds to the endowment of the Franklin W. Olin College of Engineering.

[20] Honan, William H, *$200 Million, Largest Gift Ever, Endows New Engineering College*, New York Times, Friday, June 6, 1997.

engineering education that addresses all of the concerns that were known at the time about the need for change in this field. The decision to create a new independent institution followed a four-year period of consideration of several alternatives, including the creation of a college of engineering within a fine private university that did not already have an engineering program, and the consideration of funding an existing engineering school that appeared to already have an excellent educational program for engineers. The detailed story of the founding of Olin College is available in a recent publication.[21] This account includes some history of Mr. Olin, the legacy of the F.W. Olin Foundation, the early years in which the campus was constructed, the founding faculty, staff and students were recruited, and the innovative process by which the first curriculum was developed. It ends with the awarding of the first B.S. degrees at Olin College at the inaugural commencement ceremony in May 2006.

The need for change in engineering education was well known at the time of the founding of Olin College. The National Science Foundation (NSF) had recently concluded the Engineering Education Coalitions Program which they conducted through much of the 1990s and invested several tens of millions of dollars in an effort to provoke systemic change in undergraduate education of engineers. ABET had independently committed to a sweeping revision of the accreditation process for engineering education in an effort to support these systemic changes. However, in spite of some notable successes on individual campuses and a greater awareness of the need for change, an independent assessment of the results of the NSF Coalitions program indicated that a truly systemic change had not been achieved, and results fell short of expectations.

More recently, the National Academy of Engineering published a report that reinforced the concerns about the need for systemic change, and identified specific areas that need to be strengthened in undergraduate engineering education.[22] These areas include the development of engineers with much higher levels of proficiency at teamwork, leadership, creativity and design, entrepreneurial thinking, ethical reasoning, and global contextual awareness. Since these areas are not closely related to traditional STEM subjects, they have been widely regarded as "soft skills" rather than critical knowledge and ability within faculties of engineering.

In 2009, Professor Woodie Flowers of MIT provided a keynote address[23] at the Engineer of the Future 2.0 Summit at Olin College in which he presented the results of a recent undergraduate thesis at MIT. In this thesis, a survey of nearly 700 recent MIT mechanical engineering graduates was conducted and analyzed. These results seemed to confirm the conclusions of the NAE publication[23] that

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[21] Greis, Gloria Polizzotti, (2009) From the Ground Up: The Founding and Early History of the Franklin W. Olin College of Engineering, A Bold Experiment in Engineering Education, Needham, MA: Olin College.

[22] National Academy of Engineering (2005) Educating the Engineer of 2020: Adapting Engineering Education to the New Century, Washington, DC: National Academies Press.

[23] Professor Woodie Flowers, (April 1, 2009) "*Man Who Waits for Roast Duck to Fly Into Mouth Must Wait a Very Long Time*," Engineer of the Future 2.0, keynote presentation at Summit on Transforming Engineering Education, Olin College (available on YouTube).

engineering alumni report that the list of "soft skills" as defined above are, in general, more important to their professional career than the core technical subjects that they were required to take at MIT. Of course, MIT's educational program is widely regarded as among the best in the world and their graduates are highly sought after for the most attractive and challenging technical positions. As a result, it is reasonable to expect that engineering alumni of other institutions would respond in a similar manner.

When Olin's founding faculty (a group of about ten faculty members with diverse backgrounds, ranging from physics to engineering, math, chemistry, music, biology, etc.) were first assembled in a restored farm house on the perimeter of the campus construction site in the fall of 2000, they were told they had about two years to rethink the way undergraduate engineers are educated before Olin College would offer any courses. During this period, they would not teach courses or be responsible for competing for research grants in their field. Instead, they were to devote their full efforts to rethinking the way engineers are educated. This required consideration of what the future might hold and what role engineers would need to play. They focused on creating a learning model from the ground up that would result in producing the best possible engineers for the 21st century, as they saw it.

The Olin Foundation was keenly aware that the future is certain to hold surprises and the need for continual change in the field of engineering, so the principle of continuous improvement and innovation in the educational process was adopted from the start. No faculty members at Olin hold tenure, and nothing at Olin has tenure (except the Founding Precepts which were provided by the Foundation). The College also does not have departments that are organized by academic discipline, causing all faculty meetings to be inherently interdisciplinary and focused largely on the collective business of teaching and learning. As a result, nearly everything at Olin has an "expiration date," including the curriculum. The intent here is to anticipate the need for periodic re-invention and continued change and innovation in the future.[24]

At a critical moment in the early fall of 2000, one of our founding faculty members raised a simple but profound question: "***What is an engineer?***" Also, "What does every engineer need to know? Don't we need to know this before we can develop the curriculum here?" In my approximately 25 years in engineering education to that point, no one had seriously raised this question in my presence. Obviously these are key questions that deserve very serious consideration.

We began by surveying the available definitions of engineering. Those of us with undergraduate degrees in engineering recognized that the majority of our education was devoted to the underlying applied sciences rather than the process of engineering. So, in this sense, engineering, as it is taught today, is dominated by the study of applied science. However, the

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[24] Olin College has established a number of processes that help focus the entire community on assessment and continual improvement. These include an annual faculty retreat which is focused on the effectiveness of the curriculum; involvement of students in the assessment of nearly all aspects of the learning experience; approximately weekly faculty meetings that are always focused on educational and advising process, methods, and outcomes; etc. However, implementation of this principle has not been easy and has already presented a number of challenges that have resulted in aberrations in the intended regular calendar of renewal.

Merriam-Webster Dictionary provides the following definition:

Engineer (noun): "a person who carries through an enterprise by skillful or artful contrivance"

It is interesting that this definition—presumably more representative of the general public's perception of engineers—does not even mention science, math, or technology (although it may be somewhat implicit). However, it does explicitly imply a degree of creativity or cleverness (*contrivance*), along with skill and art in the actual execution (*carries through*) of an "enterprise." One could even imagine that managing the process of establishing the enterprise may be part of this definition.

Discussions with corporate leaders often seemed to focus on the engineer in the role of project manager or product designer, where teamwork and leadership are of central importance, along with client relations, marketing and sales, budget management, time/schedule management, and integrity or quality of the final product. At the highest levels, corporate leaders sometimes refer to the engineer as the "systems architect"[5] who provides the overall vision and concept for the project and then insures its successful realization.

Perhaps because of the extensive use of the pedagogy of structured problem solving in a relentless stream of problem set after problem set in traditional core engineering courses, engineers sometimes think of themselves primarily as problem solvers. However, these problems are usually carefully framed in terms that facilitate the application of engineering sciences and mathematics to obtain specific answers. It is much less common for these problem sets to require students to begin with poorly defined but realistic situations involving many other non-technical aspects before identifying and framing the problem.

Perhaps the most basic definition of an engineer is "*one who makes*." This was the theme of the commencement address at Olin College in May of 2007, delivered by then-President Diana Chapman Walsh of Wellesley College. Her remarks identified engineers with the basic human need to "*make*", the same need for human expression and discovery that defines the arts.

In the first two years of invention of the academic program, the entire College followed a process[25] involving four deliberate steps: Discovery, Invention, Development, and Test. In the Discovery stage, we made a deliberate effort to learn best practices from other engineering institutions around the world. In particular, visits were made or hosted from about 35 other engineering schools and about 20 technology corporations. In the Invention phase, a small group of the founding faculty was assigned the responsibility to develop a proposal for the integrated Olin curriculum, for review, comment, and ratification by the entire community[26]. In the Development and Test phases, the founding faculty engaged in creating the specific educational methods and pedagogies for each aspect of the curriculum, often starting from scratch and developing original materials. Then, since these new methods and materials were untried, a special year of testing was undertaken (the **Olin Partner Year**) in which a group of 30 recent high school graduates (the **Olin Partners**) were recruited nationally to

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[25] *Invention 2000*, the first strategic plan for Olin College, available on the Olin College web site.

[26] This resulted in a very creative proposal which was presented in the form of a three-act play.

spend the 2001-02 academic year as partners with the faculty in testing the assumptions behind the new pedagogy and helping develop and refine the learning materials and approaches. The Olin Partners consisted of 15 boys and 15 girls and they lived in temporary modular housing units on the soccer field while the campus was under construction.

During the Olin Partner Year, many unusual tests were performed. For example, we tested the hypothesis that young engineering students need about two years of preparation in calculus and physics before they are able to undertake the design and construction of a significant engineering device or system. In this experiment, we assigned five recent high school graduates—none of whom had any college courses—the task of designing and building a pulse oximeter, with a time limit of five weeks. In this exercise, the students were first referred to patent literature in the library for a basic schematic diagram and explanation of the purpose and function of the device. They were told that various faculty members may provide advice if asked and otherwise were expected to chart their own course to building the device. The five week time limit was envisioned as providing a convenient reason to end the experiment in the event that the students failed to complete the task, before a post-mortem could be performed.

However, we were surprised to find that the students did not fail as expected, but instead built a functioning device that performed well against a hospital version of the device brought in for calibration at the end of the experiment. We learned two things from this experiment. First, students are indeed capable of completing independent projects of this type with no formal preparation at all in science or math. However, we also observed that the pedagogical effects of this project on the students appeared to be profound. They experienced a sense of exhilaration at exceeding their own expectations and building a device that performed well. This "***can do attitude***" appears to be an important side effect of the pedagogy of unstructured design projects. It resulted in strong motivation and commitment to completing the educational program and becoming an engineer. From this experiment we developed the sense that, in general, (1) we may be significantly under-estimating the ability of students to learn independently, and (2) this type of student engagement can result in significant changes in attitudes, behaviors, and motivations which are an important outcome in themselves.

Olin College Overview in 2010. Olin College is an undergraduate residential college offering B.S. degrees in Engineering, Electrical and Computer Engineering, and Mechanical Engineering located in Needham, Massachusetts, a quiet and upscale residential suburb of Boston. The campus consists of about 75 acres and 400,000+ square feet of attractive new facilities located adjacent to Babson College, a private business college that is well-known for programs in entrepreneurship, and about two miles from Wellesley College, a highly selective liberal arts college for women. The current enrollment is about 330, with a student population that is about 45% women[27]. The student faculty ratio is about nine-to-one, with a permanent faculty of 36. The faculty at Olin all have Ph.D. degrees from the nation's

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[27] This feature of Olin's student population is quite unusual since every student at Olin College must major in engineering and only about 18% of all undergraduate engineering majors in the U.S. are women.

top universities[28]. Olin College is committed to a vigorous program of intellectual vitality and has developed a consistent record of research expenditures of about $1 million per year, externally funded by federal agencies and private foundations.

Olin students may freely cross-enroll at no additional charge at neighboring Wellesley College, Babson College, or Brandeis University and about 1/3 of the student body is so enrolled each term. As a result of the Founding Precepts imposed upon the College by the F.W. Olin Foundation, Olin is not internally organized into academic departments and faculty members do not have tenure. Instead, faculty members are employed with renewable term contracts with a range of term lengths.

The Olin Foundation also directed the College to reward merit among students and to provide an excellent engineering education at little or no cost, independent of family resources. As a result, Olin currently provides every admitted student with an 8-semester 50% tuition scholarship based upon merit[29]. In addition, the College has a need-blind admission policy and provides full need-based aid to all admitted students. This support is made possible by a large endowment[30] which resulted almost entirely from gifts from the F.W. Olin Foundation before it dissolved. The academic quality of the Olin College student body is exceptional by every measure[31].

A particularly important aspect of Olin College is the precept requiring the College to devote itself to continuous improvement and innovation. As a result of this commitment, assessment and continuous improvement are deeply woven into the character and culture of the institution—so much so that nearly everything has an "expiration date." This includes the Bylaws and even the curriculum[32]. Olin's institutional commitment to continuous improvement and assessment was singled out for special recognition by the accreditation visiting team from the New England Association of Schools and Colleges (NEASC) in 2006[33].

As previously explained, Olin's mission is to prepare engineering innovators. We believe that requires preparing graduates who are adept at creating new concepts and enterprises that are simultaneously feasible, viable, and desirable.

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[28] Eighty percent of Olin's Engineering faculty members have Ph.D.s from graduate programs in engineering rated in the top 10 by the U.S. News & World Report, and about 70% of all of Olin's faculty members have Ph.D.s from research universities rated in the top 20 by U.S. News & World Report.

[29] From the first entering class in the fall of 2002 until the class that entered in the fall of 2009, all students enrolled at Olin received a 100% tuition scholarship.

[30] The current value of the Olin College endowment is approximately $350 million, or more than $1 million/student. This places Olin among the 10 in the nation by this metric.

[31] The median combined SAT scores of Olin's incoming students (M + V) is 1470, and on average, about 1/3 of the entering students are selected as National Merit Finalists each year.

[32] The curriculum currently expires every 7 years and must be actively review and either revised or reinstated.

[33] "*No other institution in the Team's considerable collective experience is as committed as Olin College to assessing and reassessing its performance against the eleven standards of accreditation. Moreover, the results of these assessments are employed directly in improving institutional effectiveness in that performance.*" Quoted from the NEASC Visiting Team Report for Olin College, May 1, 2006, Dr. Jon C. Strauss, Chair of the Visiting Team, and then-President of Harvey Mudd College.

This requires a learning model with a deep commitment to learning from fields well ***beyond technology***, and therefore including many topics that are at arm's length from the center of gravity of the collective Olin faculty expertise. The basic strategy for achieving this integrated exposure is provided by building a strong collaboration with neighboring institutions. In particular, Olin students find a predominant focus on subjects related to feasibility on the Olin campus, a predominant focus on subjects related to viability on the Babson campus, and substantial opportunity to explore subjects related to desirability on the Wellesley campus, along with many other topics in the liberal arts and sciences. It is the intersection of these three campuses that provides the richest learning opportunities for future innovators.

Some Features of the Current Olin College Curriculum. The Olin College curriculum is continually evolving—by design. The current incarnation provides a snapshot of the best efforts of the Olin community to provide a new paradigm for engineering education. Some of the most striking features of the program are summarized below:

- *Candidates' Weekend*: Admission to Olin requires all candidates to participate in one of several weekend interview events on campus each winter. Candidates are assigned to small teams and observed as they perform a design-build exercise[34] and develop a group presentation on a controversial topic unrelated to technology. Finally, candidates undergo individual interviews intended to explore the extent of multiple intelligences. Faculty, staff, students, and alumni participate on the evaluation teams and in the admission decisions.
- *Extensive Design Core*. Olin has rebalanced the emphasis throughout all degree programs by placing the design process on an equal footing with the applied sciences. Approximately 25% of all student credit hours are devoted to design subjects through the four-year program.
- *Corporate-sponsored Capstone Design Project (SCOPE).* All students must complete a year-long engineering design project in small teams with a corporate sponsor that provides $50,000 in support for each project. The projects require a corporate liaison engineer and often involve non-disclosure agreements and new product development.
- *Business and Entrepreneurship*. All Olin students must start and run a business for a semester in order to graduate.
- *EXPO*. At the end of each semester, every student is required to participate in the Olin EXPO in which every student must either participate in a lecture/presentation or a poster presentation for the entire campus community plus about 100 corporate and academic evaluators. The format is similar to that of a national technical meeting and feedback is provided to each student to improve communication skills.
- *Olin Self-Study*. Every student at Olin is required to complete an independent study/research project before graduation. This project requires the student to identify a question of interest,

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[34] Which is not evaluated.

develop an individual learning program to find the answer, and obtain an expert assessment to make sure that the correct answer has been obtained[35].

- *AHS/E! Capstone Project*. Every student must complete a semester-long capstone project of their own design in either the arts, humanities, and social sciences (AHS) or in entrepreneurship (E!).
- *Study Away in Junior Year*. The Olin program was specifically designed so that any student can plan his/her academic program to study away in the junior year and still graduate in four years. Currently 25 - 30% of Olin students take advantage of this opportunity.
- *Summer Internships*. All Olin students are encouraged to pursue summer internships in technology companies or in university research laboratories, beginning at the end of the first year. Nearly all Olin students have done this at least once before graduation.
- *Nine Competencies Across All Four Years*. Olin requires every student to track his/her progress from year-to-year in each of nine independent competencies: quantitative analysis, qualitative analysis, teamwork, communication, life-long learning, contextual analysis, design, problem diagnosis, and opportunity assessment.

While many engineering programs offer some of the same kinds of opportunities, Olin requires all students to complete each of these components. This uniformity of student experience contributes to the unique learning culture that is largely responsible for the high levels of student engagement and independent learning. Other very important factors include the emphasis on intrinsic student motivation throughout the academic program.

It is this learning culture that is most important. The role of the faculty and curriculum is to create this special learning culture. Another institution might attempt to duplicate the Olin model by copying the specific courses and programs outlined above. However, unless the learning culture is duplicated, the results will not be the same[36].

Charles Vest, President of the National Academy of Engineering, has explained this point very well: *"Making universities and engineering schools exciting, creative, adventurous, rigorous, demanding, and empowering milieus is more important than specifying curricular details."*[37]

Reflections on Eight Years of Experience with the Olin Learning Model. Olin offered its first courses to freshman students in the Fall of 2002. Reflecting back on 16 semesters of experience with this program and 5 graduating classes, I would say that overall we are quite pleased with

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[35] This is an important aspect of our effort to teach students how to become independent and adaptive learners.

[36] For example, MIT has created a remarkable Open Course Ware (OCW) Project in which nearly 2,000 of their courses—including syllabi, reading assignments, exercises, exams, etc.—are available at no cost on their web site. However, another institution that attempts to implement these courses directly is unlikely to duplicate the MIT learning culture.

[37] Charles Vest, prepared remarks at Harvard University, September 20, 2007.

the results. In general, the students have exceeded our early expectations in their abilities as young engineers and innovators. Furthermore, they are receiving excellent post-graduate opportunities[38] and the early feedback from employers and supervisors is that Olin alumni have distinguished themselves among their peers in various venues.

Qualitatively, we feel that the Olin learning model has resulted in intense student engagement in their education, increased motivation for learning, increased independence and autonomy, strong potential for leadership, strong interest in entrepreneurial endeavors, high levels of experience and proficiency in teamwork, and a striking ability to "stand and deliver", manage projects, and work with ill-structured problems.

The mission of Olin and its method of attracting faculty and staff have also resulted in a pervasive interest in and commitment to change in education among the faculty and staff.

On the other hand, we have some nagging concerns and worries at this point, including the possibility that Olin graduates—because of our intense focus on innovation in team-based projects—may display a slightly diminished long-term interest in purely theoretical subjects. A related concern is whether we have achieved the right balance in emphasis between design topics on the one hand, and advanced theoretical/analytical subjects on the other. Similarly we are concerned about the balance between qualitative and quantitative design subjects. The emphasis on entrepreneurial thought and action seems to have resulted in a slight preference for small start-up companies among our graduates. Answers to these questions cannot be obtained without objective data from longitudinal studies of our alumni. We are in the process of developing a set of metrics this year.

We are also concerned about the scalability of the learning model and the extent to which it may be influential in larger universities. To explore this important issue, Olin College entered into a partnership with the University of Illinois at Urbana-Champaign two years ago. The early results from this project are quite encouraging. Olin and Illinois faculty have been working side-by-side to develop parallel learning elements to several Olin courses and have implemented them in pilot courses at Illinois. The results have been sufficiently successful that Illinois plans to expand the project to include 300 students next fall.

Finally, since Olin College is no longer an early-stage start-up institution, I personally fear a growing resistance to change. This resistance is natural and part of the maturation of the institution. In the first year of the development of Olin's program I visited one of the only

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[38] For example, a survey of the alumni from 2006 – 2009 revealed that 99% are either employed or pursuing graduate study. Given that the national unemployment rate is currently above 10%, we consider this result to be excellent. In addition, this year's graduating class of about 85 students included three who won Fulbright Scholarships, three who won NSF doctoral fellowships (and another three who were selected for "honorable mention" for this award), and three who were accepted directly into Harvard Business School. About 35% of this year's graduating class went on to graduate school, with most of them pursuing graduate degrees in engineering or science from the top ten engineering schools in the U.S., although several are pursuing medicine, business, or law instead. Last December the first Olin alumnus completed a Ph.D.—in Physics from Oxford University; the second and third completed Ph.D.s from Columbia University and the University of California at Berkeley, respectively (in Mathematics Education and in Materials Science).

experienced academic leaders in the country to have personally led the effort to start a new undergraduate science and engineering college. His name is Joseph Platt, and he is the Founding President of Harvey Mudd College. Joe passed along a key observation from his experience at HMC: *"There is no more powerful force for conservatism, than having something to conserve!"* In the first years of Olin, we had nothing to conserve, but in just eight short years we have begun to believe that we have developed something special. As a result, there is a growing attitude on campus that we could lose a great deal if we make any big changes in our program.

Ultimately, our success as an institution devoted to innovation will be determined by our ability to remain open to change. The learning model that is best suited to today's world is unlikely to be optimal for the world of 10 or 20 years from now.

Student Engagement and Learning Outcomes. Olin College's pedagogical approach is distinctive, with more emphasis on pedagogies of engagement than most other engineering schools. In order to assess whether our learning model is producing any measurable difference in student learning outcomes, it is necessary to develop some objective methods of assessment. Perhaps the most direct method is to monitor the longitudinal career outcomes for our graduates. However, it is too early in our history for this approach since we have only five graduating classes at this stage.

An interesting indirect assessment is provided by the National Survey of Student Engagement (NSSE). This national assessment was developed at Indiana University[18] by researchers in education to measure the degree to which students are engaged in educational activities that correlate with favorable long-term learning outcomes. In general, the research indicates that the more students take responsibility for their own education, demonstrate enthusiasm and are engaged in their studies, the more they learn and the more they continue to learn independently. The NSSE survey involves confidential surveys of thousands of university students each year about their activities, attitudes, and experiences in their local learning environment. The questionnaire covers five major areas, including level of academic challenge, active and collaborative learning, student-faculty interaction, enriching educational experiences, and supportive campus environment. Each year the NSSE survey involves more than 500 colleges and universities nationwide, and about a half-million students. The results are now published annually by USA Today newspaper.

Olin College has participated in the NSSE survey each year for the last several years. The results indicate that our students are substantially more engaged in these positive learning outcomes that students at similar stages in their program at other universities. In fact, the overall results indicate that students at Olin College place above the 90th percentile in nine out of ten of the indicators in the NSSE survey, in comparison with all colleges and universities that participated in the survey. When the data are normalized by subtracting the global mean and dividing by the global standard deviation, the results for Olin College range from about ½ to 2 standard deviations above the global mean values in each category. Results of this type have been obtained every year for the last several years.

While these results are only an indirect indicator, they are so consistent across all the metrics that it is difficult to avoid the conclusion that something unusual is happening within our program. We are anxious to explore the correlations between these NSSE results and the longitudinal measure of career outcomes for our graduates in future years. I suspect that other institutions that shift toward greater use of pedagogies of engagement will also experience an increase in their NSSE scores.

Richard K. Miller was appointed the President and first employee of the Franklin W. Olin College of Engineering in 1999, where he also holds an appointment as Professor of Mechanical Engineering. He served as Dean of the College of Engineering at the University of Iowa from 1992-1999, and spent the previous 17 years on the engineering faculties at the University of Southern California (where he held the position of Associate Dean for Academic Affairs) and the University of California, Santa Barbara.

Dr. Miller's research interests are in applied mechanics and he is the author or co-author of about 100 reviewed journal articles and other technical publications. The recipient of five teaching awards at two universities, he is a past chair of the Engineering Advisory Committee at NSF, past chair of the AITU, a member of the Visiting Committee at the School of Engineering and Applied Sciences at Harvard University, and has been a consultant to the World Bank on the establishment of new academic institutions, among other activities.

A native Californian, Dr. Miller earned his B.S. degree in Aerospace Engineering in 1971 from the University of California, Davis, where he received the 2002 Distinguished Engineering Alumnus Award. In 1972, he earned his M.S. degree in Mechanical Engineering from the Massachusetts Institute of Technology. In 1976 he earned his Ph.D. in Applied Mechanics from the California Institute of Technology

Meta-structures for integrating engineering and liberal arts education and research

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ABSTRACT: This paper proposes that all academic fields (arts, humanities, sciences and engineering) should aim to develop a balanced distribution of disciplinary, multi-, inter- and trans- disciplinary activities. The combinations of such distributions will give rise to a post-disciplinary liberal education that can prepare problems solvers who can tackle the complex issues of the 21st century. Problem-based learning and outcome-based curricula can serve as integrative structures across the different areas of knowledge. In this context deep knowledge will take both homogeneous and heterogeneous forms. Post-disciplinary liberal education necessitates enhanced student agency, embracing of emergence by faculty and students and continuous change in curricula. It also demands new assessment structures and evaluation of individuals in the context of teams.

Introduction

President Miller put forth an exciting vision for contemporary engineering education. It is driven by societal need rather than self-referential disciplinary, academic concerns. Our society is dealing with problems that are too complex and too dynamic to be solved by limited knowledge spaces, local activities or fixed approaches [1]. These problems require distributed and dynamic solutions developed by teams of people with diverse expertise [2]. The majority of the individual members of these teams will be post-disciplinary.

Let us for now define post-disciplinary as an education that goes beyond disciplinary models while also integrating disciplinary practice (we will return to this definition later). To prepare post-disciplinary engineers that are good problem solvers there is a need to change engineering education. The new engineering education needs to be more problem driven and needs to integrate components of liberal arts education. These components will give engineers the humanistic understanding necessary for solving problems, such as sustainability, that owe much of their complexity to human behavior. Liberal arts education will also help engineers develop the necessary intellectual, emotional and communication skills for working in teams and for embracing concepts and functions of collective success. The proposed training however, cannot be accomplished by integrating traditional liberal arts education into the kind of innovative engineering curriculum described by president Miller. For example, an engineer taking a traditional music course on the history of rock music or playing in the college orchestra does not immediately become a better problem solver. In fact, mixing traditional liberal arts education with traditional engineering education may reinforce nonproductive stereotypes that treat the arts and humanities as fun, creative work and engineering as serious, dry, non-humanistic work. Such approaches hinder the transference of deep knowledge between the disciplines and undermine integrative approaches that can lead to problem solving. The training of true post-disciplinary engineers must integrate a new type of liberal arts education that is driven by the same goals as the proposed new engineering education; the need to prepare post-disciplinary problem solvers.

Developing a problem driven liberal arts education can be more challenging than innovating engineering education. Many of the core liberal art fields at the university setting see their role as primarily non-utilitarian and tied to a “push” model of knowledge. For example, some traditional arts and humanities departments focus on teaching a narrow disciplinary canon. They may teach students a whole series of great books or works of art because they believe that at some point the students will need this knowledge. This is what John Hagel and his collaborators would describe as the “push” model of knowledge [3]. The “push” model may be adequate for times of slow changing knowledge but is probably unproductive in times of fast and dynamic evolution of knowledge. The other impediment hindering a problem driven education in arts and humanities is that these fields have not engaged utilitarian issues to the extent they are engaged by engineering. For example, the inclusion of music training in a liberal arts education is based on the notion that the practice of music makes a student a more complete human being and a better member of a balanced society. However, traditional music schools do not focus much of their energy on providing tangible evidence for this notion. This makes music and other arts units vulnerable during hard financial times where funding gravitates to efforts with solid evidence of tangible outcomes. Liberal arts units could reinforce the importance of their role in a modern university by reworking their curricula so as to directly connect a portion of their outcomes to collaborative solutions of complex societal problems. This approach will help innovate liberal arts curricula and make liberal arts units prime partners in the post-disciplinary training of STEM experts.

What I am proposing is that a contemporary liberal education requires that all fields in a university, not just engineering, change their distribution of activities. All fields (arts, humanities, sciences and engineering) need to reduce emphasis on models that primarily train students in the basic concepts of a single discipline or in the canon of a narrow field of knowledge (figure 1a). They need to develop a distribution of activities that address disciplinary training as well as multi, inter and trans disciplinary practices related to the field (figure 1b). It is understood that some disciplines like literature or music may not have as much activity in transdisciplinary problem solving as engineering but all fields need to have some baseline level of activity across the continuum from disciplinary to transdisciplinary. The combination of such distributed activity by all fields of knowledge can support the emergence of a post-disciplinary liberal education. Such education will train problem solvers with different types of expertise who can work in teams to solve complex societal problems.

I want to present four principles that can support the emergence of the proposed post-disciplinary liberal education:

- rethinking of the depth vs. breadth duality
- use of organizational structures that transcend disciplines: focusing on problem-based learning and outcome-based education
- empowering student agency (combining bottom-up and top-down approaches) and embracing emergent structures and continuous evolution
- implementing post-disciplinary assessment and evaluation structures

In the rest of the presentation, I will discuss these four principles in more detail. I will illustrate the discussion with examples from the graduate and undergraduate curricula at the School of Arts, Media and Engineering (AME) at Arizona State University (ASU), and from the

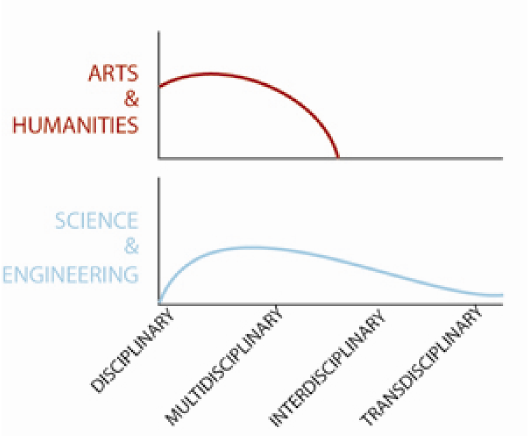

Figure 1a:
Distribution of activities in disciplinary education

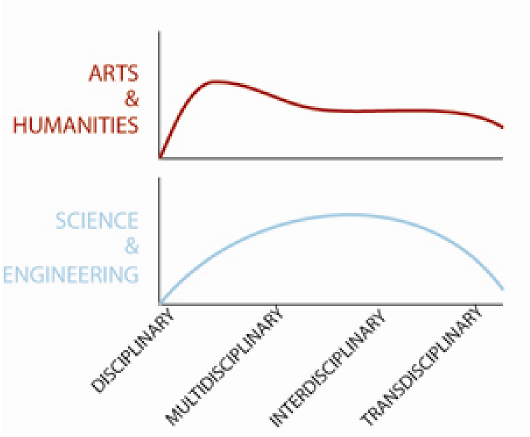

Figure 1b:
Distribution of activities in post-disciplinary education

operation of my own transdisciplinary research group that works on mixed reality rehabilitation systems for stroke survivors.

Most useful, interesting knowledge has depth. In the opening of his book " A Very Short Introduction to Mathematics" [4], Timothy Gowers discusses how the understanding of a Hilbert space requires knowledge of a whole hierarchy of lower level concepts like vector space, inner product, Cauchy sequence and convergence. Similar hierarchies of knowledge exist in the arts. For example, understanding the seminal handling of counterpoint in JS Bach's music, requires knowledge of 16th and 18th century counterpoint, which necessitates knowledge of tonal theory, which requires knowledge of the basic concepts of music such as notes, scales, rhythms, meter etc. However, it is not necessary for an expert Bach analyst to also be an expert violinist, and an expert violinist does not need to be an expert Bach analyst. Both the master violinist and the Bach theorist share some common knowledge especially of the basics of music, but at some point their paths diverge. What is being proposed is that we can look at bodies of interdependent knowledge as tree structures. These are structures where several knowledge paths have the same root or lower level requirements. However, in a tree structure it is not necessary to know all branches of a knowledge tree to be able to handle one of its branches. Scott Page, in his book Difference [5], presents the overall idea of knowledge trees and gives a simple example: "*if a person learns how to take derivatives, he can then learn how to perform integration or how to solve differential equations. Yet to solve differential equations, he need not know how to perform integration and to perform integration he need not know how to solve differential equations*". Figure 2 gives an illustration of a tree of knowledge as presented by Page. It is interesting to note that Page calls knowledge components "Tools" thus emphasizing that knowledge components and trees of knowledge are not an end into themselves but something that is used for solving real-world problems.

The idea of trees of knowledge supports the concept that deep knowledge can be achieved though a "pull" model. A student can become interested in a particular topic and learn the branch of a knowledge tree related to that topic without having to learn the whole tree. This approach can release our education structures from "push" models of learning and from overprescribed curricula that aim to have students learn most branches of all key trees in a discipline. Since the student can achieve deep learning of a branch in a discipline without

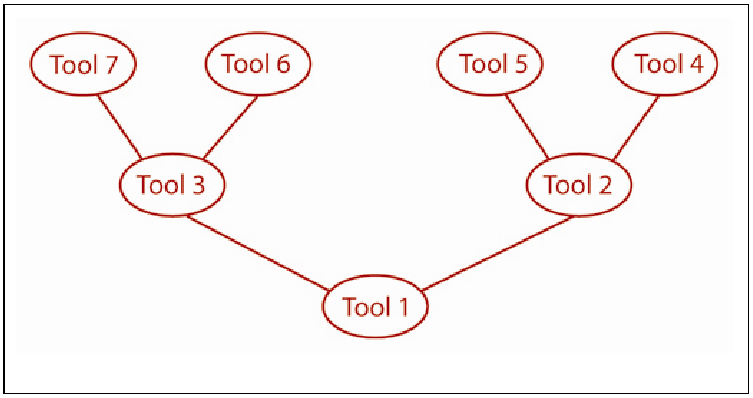

Figure 2: A tree of knowledge components (Tools) from Page [5]

having to learn the whole discipline, this also opens up time for the student to gain deep knowledge of branches across disciplines. It is of course important to make a distinction here. If someone wants to be an expert in a disciplinary area, like an expert on Bach's music, then they will probably have to learn many branches of knowledge in that discipline. However, if someone wants to be a complex problem solver in an area like sustainability, then they need to learn the branches of knowledge that relate to the problems they are solving regardless where those branches come from in terms of disciplinary roots. Contrary to some traditional beliefs, the knowledge of the sustainability expert will be as deep as the knowledge of our music expert.

The understanding of a knowledge area branch can be improved by studying other branches of the same knowledge tree but also by studying branches of other trees. There is little comparative evidence on whether the homogeneous or heterogeneous branches approach (or a combination of those approaches) better enhances understanding of individual branches. The reason there is little comparative evidence is that most of our education focuses on covering collections of disciplinary trees rather than learning of branches across diverse trees. However, we do know that people with diverse knowledge can be excellent in certain branches of knowledge and produce highly impactful, innovative outcomes. The evolution of arts and sciences and recent literature on creativity confirm a strong connection between diverse perspectives and innovation [5, 6, 7, 8, 9]. Leonardo DaVinci and Michelangelo are obvious early examples of expertise combined with diversity. They were considered excellent painters even though they were involved in diverse activities including, in the case of Leonardo, the design of war machines. Florence Nightingale was a nurse, an author and a statistician. She combined her diverse skills to define the basis for modern nursing and even initiate some of the ideas for evidence based medicine [10]. In a more recent example, Ianis Xenakis, who combined knowledge in engineering, architecture and music, produced significant breakthroughs in modern arts and design. His most significant contribution was the formalized use of stochastic procedures for music and visual composition [11]. The subject of open form was prevalent during his times, but the insights Xenakis produced escaped many of his highly talented, but traditionally trained contemporary colleagues.

Even though we have evidence of the connection between diverse training and innovation, in many education circles diverse training is still treated as lacking rigor. Many interdisciplinary education activities aim to provide the student with a combination of depth and breadth. This description sounds innocuous until one understands that in most cases depth is associated with exhaustive knowledge of a discipline and breadth with surface knowledge of some other areas and thus superficial. This approach excludes the possibility of deep diverse knowledge: of someone knowing deep branches of knowledge across different areas. More importantly, this approach ignores historical evidence showing that new deep knowledge can result from knowledge fusion. For example, as our world evolved with increasing speed in the past 300 years, existing areas of knowledge were combined to set the basis for new engineering disciplines (electrical engineering, computer science, bioengineering etc). These new disciplines developed rigor and depth specific to their problem sets. Of course, the single person expertise that might have been possible for earlier synthesized areas like electrical engineering is becoming much harder for new areas of fused knowledge. As the complexity of our world is increasing, we see the emergence of areas like biodesign and sustainability, where the depth and diversity of knowledge trees involved is way too large for one person to master. So each person has to pick which branches they will learn deeply, which branches they might only learn the basics for, and which branches they may not cover at all. These individuals need to then form teams that combine their individual skills into an integrated whole covering all needed areas of expertise. In this scenario, the complete deep knowledge of the new synthesized field rests with the team, not an individual. Teams covering new complex areas are necessarily diverse and thus collaboration is hard. All members of these teams need to be experts in some branches, highly skilled in integration of diverse principles, and good collaborators. We can conclude therefore, that development of new knowledge through interdisciplinary collaboration is anything but a surface venture.

Many of the artificial depth-breadth dualities we see in academia assume that knowledge is static. I therefore want to propose an model of evolving knowledge that is more fitted to contemporary reality and minimizes the need for depth-breadth discussions. The model is illustrated in figure 3. Let us imagine a circular space of knowledge. Established areas of knowledge form the defining perimeter of the circle, with each large category of knowledge (science, humanities, etc) represented by an arch. We can call the perimeter the disciplinary space. The area encompassed by the perimeter becomes the interaction space; where different branches of established knowledge interact and integrate. We can call this middle area the interdisciplinary space. Interdisciplinary interactions inform the gradual evolution of established areas but also form new areas of knowledge and related expertise. We will call these new areas transdisciplinary. As the emergent activity in transdisciplinary areas slows, these areas either get consumed into expanded notions of established areas or they become established disciplines in themselves. With older areas of fused knowledge integrating into the disciplinary horizon the interaction space opens up for new inter and transdisciplinary adventures.

How would the training of an individual student look in this model? Let us assume for ease of discussion that each student can only learn 10 deep branches of knowledge. The distribution of those 10 branches for each type of student to interdisciplinary interaction and integration. Finally a transdisciplinary student will have branches in a new area of knowledge combined with branches related to interdisciplinary integration and some disciplinary branches. All these students have an equal amount of deep


Figure 3a:
established knowledge


Figure 3b:
interdisciplinary interaction

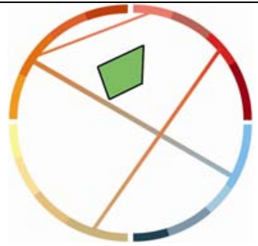
Figure 3c:
transdisciplinary
emergence

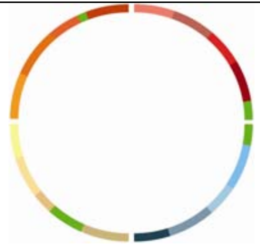
Figure 3d:
integration of new
knowledge into established
knowledge

Figure 4a:
disciplinary student

Figure 4b:
multidisciplinary student

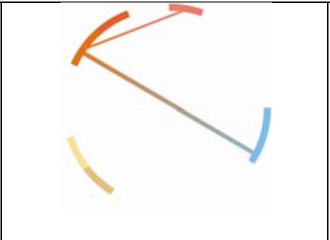

Figure 4c:
interdisciplinary student

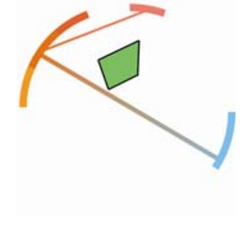

Figure 4d:
transdisciplinary

knowledge but a different distribution (figure 4 gives an example visualization of the distributions). Together, these students can comprise the citizenry of post-disciplinary liberal education.

This proposed model offers students countless paths for structuring an education that fits their interests. However, there are also challenges. The model requires a modular curriculum from all participating units and a gradual abandonment of strict sequences of three-credit courses. Traditional organizational structures cannot simply be abandoned without replacements plans. New structures are needed that help faculty and students "pull" useful, coherent and meaningful liberal education experiences for the student from this open space. I propose two key meta-structures for achieving this goal: problem-based learning and outcome-based education.

Problem-based learning and post-disciplinary liberal education

There is strong evidence that problem-based learning promotes active learning and enhances holistic approaches to complex issues [12]. In the context of post-liberal education, structuring education and research experiences around complex problems has another very important benefit. It elevates processes and outcomes past disciplinary norms and expectations while allowing ample space for the integration of disciplinary knowledge. What I am proposing is that a student enrolling in the university should be asked to choose a set of problems rather than a disciplinary label. We should replace the traditional question of "what do you want to be?" with the question: "what kind of problems do you want to solve?" The choice of problems can be facilitated by testing for outcomes of societal significance. We should also ask: "how will solving these problems make the world a better place? How will it improve the human experience?" Focusing on outcomes of societal significance pushes the student away from toy problems and towards complex contemporary problems. When dealing with complex problems, diverse points of view and collaboration become a necessity. The participants recognize and embrace the need for post-disciplinary education and collective success. Problem based learning also invites post-disciplinary assessment approaches. Participating problem solvers don't ask whether a solution is good engineering or good art. They consider whether the solution addresses the problem.

I want to give a concrete example of the use of a contemporary problem to organize the research and education experience of a cohort of 20 graduate students of diverse backgrounds and interests at the School of Arts, Media and Engineering. The overall problem area is improving stroke rehabilitation through the use of new technologies. Our team's focus is developing adaptive mixed reality rehabilitation systems for stroke survivors for use at the clinical setting and the home. We consider the problem area as transdisciplinary and we involve in the description and solution of the problem not just academics but also clinical practitioners and the actual stakeholders; the stroke survivors and their caregivers. We end up with a holistic understanding of the problem but also a complex overall description that lines up well with the World Health Organization International Classification of Functioning Model [13]. In that model (figure 5) disability is connected to a network of influences: health condition, body functions and structure, participation, personal factors and environmental factors (external influences that range from socio-economic issues to the presence of a caregiver/partner). Complicating the issue is the minimal amount of support from health insurance for long-term rehabilitation. Usually, insurance support ends six months post-stroke whereas effective rehabilitation may need 2-3 years. To give a sense of the magnitude of the problem we should mention than more than 700,000 Americans are affected by stroke each year.

Our lab is developing adaptive, mixed reality rehabilitation (AMRR) systems that integrate traditional rehabilitation and motor learning theories with motion capture and sensing technologies, smart physical objects, and interactive computer graphics and sound. The systems provide real-time, intuitive, and integrated audio and visual feedback representative of goal accomplishment (e.g. did I get to the target?), activity performance (e.g. how were my reaching speed and trajectory?), and body function (e.g. did I use shoulder or torso compensation?), during a reach and grasp task. The participant (the stroke survivor) uses the feedback for self-assessment and the development of improved movement strategies. Thus the participant becomes actively engaged in her own training. The system also provides an overall quantitative evaluation of the movement and of individual movement components. The therapist can adapt the system at any time to customize the therapy to each participant's needs and progress, as informed by the therapist's observations and the quantitative assessment.

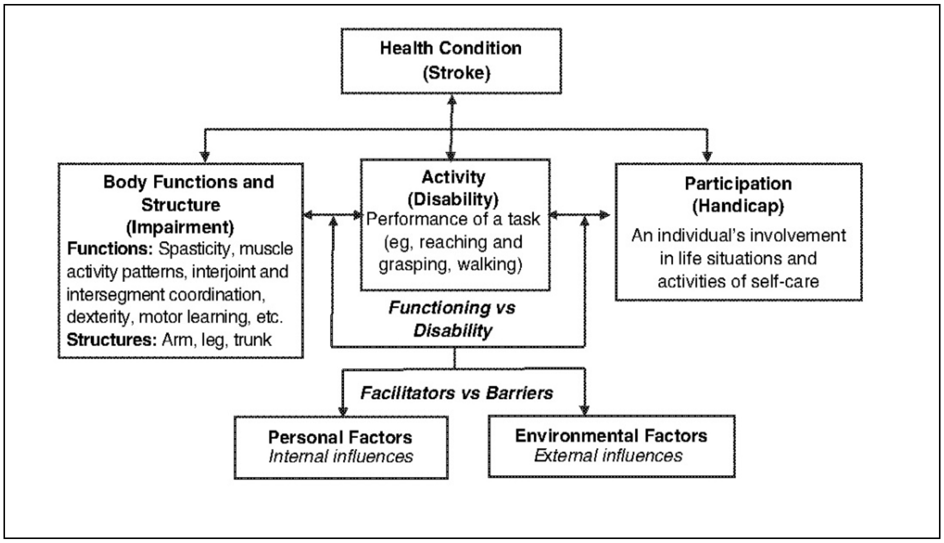

Figure 5: The WHO Classification of Functioning model by Levin and all [13]

The following link provides an audiovisual example of the use of the system in a clinical setting (http://vimeo.com/12518365). Feedback is provided on an LCD screen and two speakers. Each reach begins with a digital image appearing on the screen, which breaks apart into many minute segments of the image, called particles. As the participant moves her hand towards a target location, the hand's forward movement pushes the particles back to reassemble the image and simultaneously executes a musical phrase. Visual feedback communicates spatial aspects of activity level movement features (e.g. trajectory deviation stretches the image in the direction of deviation) (see figure. 6). Audio feedback communicates temporal aspects of activity components (e.g. endpoint speed controls the musical rhythm) and provides indicators for body function (e.g. shoulder compensation activates a unique sound indicator). The amount of error required to produce each type of feedback (feedback sensitivity) can be independently adjusted to fit the therapy needs of each participant. This system is currently being tested at the Rhodes Rehabilitation Institute of Banner Baywood Medical Center. We are also developing a home version of the system that stroke survivors can use for therapy in the home for as long as necessary with remote supervision by a therapist. Publications describing the systems in more detail and presenting results from studies can be found on the project website (http://ame2.asu.edu/projects/mrrehab/).

The development of this system requires expertise from many areas: medicine and rehabilitation, bioengineering, computer science, electrical engineering, visual arts and animation, music and sound design, cognitive science and psychology, sociology, industrial design and even gaming (especially for long term use at the home). The graduate students participating in this research group have a background in at least one of those areas and many of them in two (e.g. bioengineering and visual art, or computer

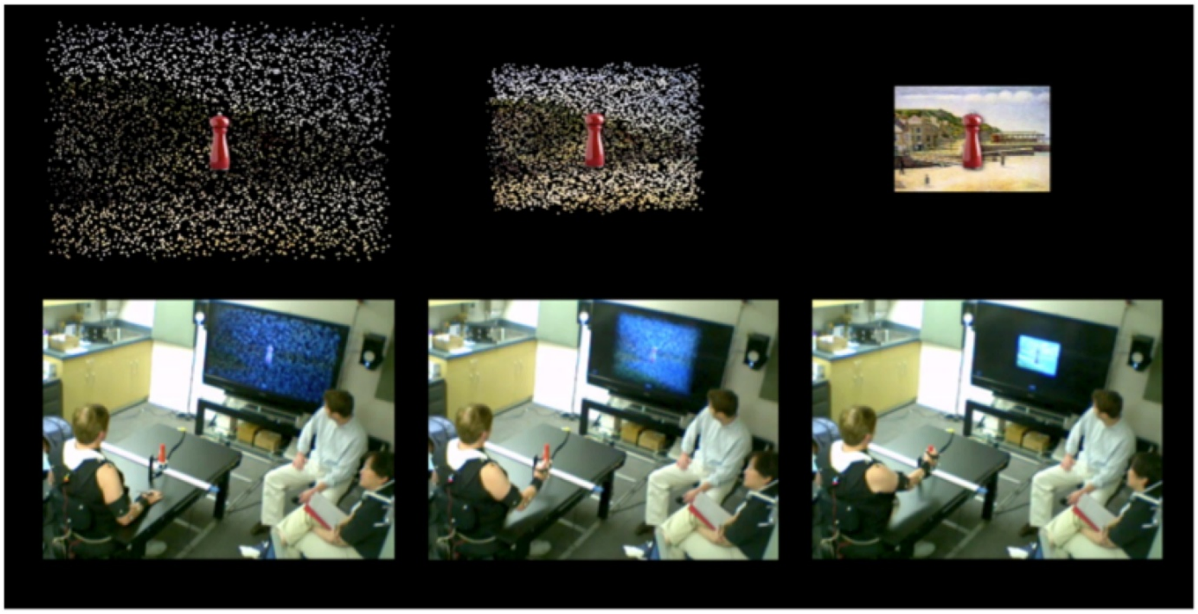

Figure 6: Illustration of the interactive visual feedback. As the stroke survivor performs a reach, her movement pushes particles on the screen back in space to form an image.

A current inter/transdisciplinary focus of our work is the use of probabilistic networks for structuring and evaluating the relationship between training, feedback and movement learning**.** Within this context, media arts insights have helped improve the computational modeling processes and computational and neuroscience insights have helped improve the media composition processes. Our media arts experts use compositional methods that integrate individual feedback components into a coherent form that parallels the structure of the movement. Interactions between movement components and feedback components are categorized as explicit, implicit or extracted or combinations of those interactions. These insights on interactive form have promoted the development of computational models that go beyond one to one movement/feedback correlations found in traditional biofeedback scenarios. The computational experts of our team have developed schemes that track in parallel one to one, one to many and many to many movement/feedback correlations. The models also track propagations of direct correlations to other components and the effect of hidden nodes. All correlations also consider the effect of movement structure (movement to movement correlations). These computational schemes help all developers evaluate and improve the system and have in turn greatly influenced the media composition process. The digital media feedback sequences have become highly modular allowing any feedback scenario to be followed by almost any other scenario. The sequencing is based on the probability graphs tracking the progress of the training and the interrelationships between feedback and learning. Insights from clinicians and neuroscientists have also helped the team develop a better understanding of non-linearities in motor learning for rehabilitation [14]. This has encouraged the use of multiple time frames for the assessment and structuring of the training and the development of different feedback schemes per time frame. At small time scales, media feedback informs performance of individual movement components. Middle time-scale feedback establishes strategies for overall improvement of movement. Larger time-scale feedback takes the form of audiovisual storytelling with the evolution of the story indicating overall progress by the stroke survivor. The success of the media art forms is not judged by the aesthetic results produced by the media authors but by the engagement and learning exhibited by the stroke survivor. The team has also developed a visualization tool to help clinicians and system developers track in real time the sequence and distribution of interactive training scenarios and their relationship to changes in the key movement components of the stroke survivor. This tool can be seen at once as a modeling tool, a composition tool or an assessment tool. More accurately it should be seen as a transdisciplinary tool for interactive mediated training.

Seeing such advancements, students in our team gain appreciation of the benefits of diverse collaboration for the team and for each individual's work. Students develop the necessary trust and belief in interdependencies that are crucial for successful teamwork [15, 16]. Furthermore, they begin to integrate personal success with collective success. Finally, seeing the progress of the stroke survivors reassures the students of the validity and importance of their work in terms of contributions to society. The development of these beliefs and operational processes is a key part of the training of a post-disciplinary student.

Outcome-based post-disciplinary liberal education

I have presented above an example of post-disciplinary training at the graduate level. The students currently involved in such training have primarily disciplinary or multidisciplinary preparation but little experience with inter- or transdisciplinary work. Students with a truly post-disciplinary undergraduate liberal education would be much better prepared for the graduate work just described and for advanced problem solving overall. The expectation however, cannot be that students will be prepared in the exact area of their graduate research. Undergraduate liberal education programs need to be broad and cannot be constructed around narrow problems. However, grand challenge areas like sustainability, energy, biodesign or in the case of my own work, digital culture, can act as reference frameworks for structuring broad, undergraduate post-disciplinary liberal education programs. An outcomes based approach should be taken in organizing such programs. The different areas of knowledge that can contribute to a grand challenge should collaborate to develop a common list of proficiencies that students interested in this challenge should possess. Then, course-work and research projects should be developed by all partners using these proficiencies as prerequisites and outcomes.

We recently used this approach at ASU to structure a post-disciplinary curriculum on digital culture (http://herbergerinstitute.asu.edu/degrees/digital_culture). The broad goal of the curriculum is to study how new media can improve the way we live, learn, create and communicate. Representatives from fifteen disciplines spanning arts, design, engineering, education and the social and behavioral sciences got together and developed a list of 25 digital culture proficiencies such as form and composition, modeling and inference, social mechanisms and understanding, and improvisation and rapid prototyping. All 25 proficiencies can be used at the 100, 200, 300 or 400 levels. Forty courses, covering levels from 100 to 400, have been developed by the participating units. Each course has different combinations of three to four digital culture proficiencies as its prerequisites and outcomes. The courses are organized in six large categories: core digital culture, media arts, media engineering, general digital culture, historical/theoretical, collaborative projects/capstone experience. Two more categories of courses complete the degree map: general studies and disciplinary core. Students are given a number of credits per category necessary for completing a degree. Depending on the degree (BA, BS etc), the amount of credits per category varies and so does the disciplinary core (students can do their disciplinary core in arts, design or engineering). Because all digital culture courses are interconnected by the common proficiencies, students have numerous choices of paths for completing the required digital culture hours and for constructing their preferred networks of proficiencies.

When developing individual courses for such a curriculum, faculty should adhere to the basic principles outlined in this talk. Courses should integrate collaborative problem solving. Coursework must be modular. Courses should cover branches of knowledge without expectation that students know all related branches of a tree or all related disciplinary trees. Subjects should be approached from a broad perspective thus allowing students with different preparations to attend each course. Faculty should not focus only on proficiencies familiar to their discipline but should develop courses that reveal useful correspondences between the diverse proficiencies of a grand challenge area. Let me expand on this last idea, as it is critical.

We discussed earlier how a mediated rehabilitation project can leverage interactions between modeling and inference (which may be considered primarily an engineering proficiency) and form and composition (which may be considered primarily an arts or design proficiency). I want to now use a research project by Keith Sawyer [17] to show how a theater improvisation project can allow a course to cover four diverse digital culture proficiencies. Sawyer asked two groups of professional actors (groups A and B) to create two improvised plays. Actors in group A were allowed to step out of character and use “director talk” to make decisions about the structure of the play. In group B however, all metapragmatic negotiations about the structure of the play had to be accomplished while speaking in character. In his analysis Sawyer found that the play developed by group A had a complex plot with interwoven subplots but weak character development and relationships. In contrast, the play of group B had a simple plot but emphasized character and relationship development.

Running this project in class and approaching it in parallel as a form and composition, modeling and inference, social mechanisms and understanding, and improvisation and rapid prototyping problem, can produce deep insights about the project and its process, elevate the student’s understanding of these four proficiencies and illuminate connections and interactions between different areas of knowledge. Digital capture and analysis of some of the project parameters can also be added. The captured parameters can range from simple ones, like time of participation of a character or time of interaction of two characters, to more complex ones (searching for keywords or analyzing intonation and rhythm of the dialogues). Display of results to actors in real-time and off-line can produce further insights on all aspects of the project while also investigating the role and effect of digital technology in complex human activities.

Empowering student agency and embracing emergent structures

Although the high level structures of a post-disciplinary curriculum need to be prepared by the faculty, the curriculum must encourage student agency and participation. Students should be able to develop their own education paths within the high level structures put in place by the faculty. Direct student input and patterns of student activity should be considered in the assessment and evolution of the curriculum.

I want to discuss four tools we are putting in place to help students participate in the structuring of their education in digital culture. The first tool allows students to explore different paths for completing their digital culture degree. The student logs into the system and creates a path name. She then begins to explore courses and paths between courses. Let us run a quick example. While exploring, the student becomes interested in the 200 level course “Hybrid Action: Physical Intelligence in Digital Culture” offered by the School of Dance. She sees that she cannot add the course to her path because she is missing the proficiencies of Collaborative Principles and Essay Writing. She chooses each missing proficiency and the map reorganizes to show which 100 level courses offer them. She chooses an AME course and an English course to get these two proficiencies. The courses get added to the fall and spring semesters of her first year. She can then add the Dance course in the fall semester of her second year. She follows a similar process to add a computer science visualization course for her junior year (the course requires proficiencies she can get by signing up for an animation course offered by the School of Theater and Film in her sophomore year). The student can continue to add more steps (courses) to this path, create and compare different variations of the path or just explore new paths. This tool, developed by Loren Olson, is already online and being used by our students.

We are in the process of developing three more tools to help students, faculty and advisors structure each student's experience. The first tool takes each path developed by a student and matches it to the formal degree map. The student and advisor can use this tool to monitor degree completion and adjust the student's preferred paths to better meet degree requirements. The second tool extracts networks of proficiencies for each path. It shows the proficiencies each path will provide and the volume of each of the proficiencies in the network (how many times the student will have covered each proficiency through their selected courses). We plan to track student placement and to work with human resource offices in key digital culture related companies to establish correspondences between networks of proficiencies completed by students and hiring patterns in industry. Through this process we also want to display to students that there are many different paths to each type of career. We are also hoping that our curriculum can produce students and groups of students that will start their own companies and trends in digital culture. We plan to use our tools to extract networks of proficiencies that support entrepreneurial behaviors. Finally, our third tool is a social networking tool for digital culture. For each course on our map we plan to have recommendations by faculty and students regarding other courses that connect well to that course both in terms of preparatory steps for the course and consequent steps after the course is completed. We will also have automated recommendations (i.e. "other students who took this course also took these courses"). Through this tool students will be able to compare their paths to paths of other students who are willing to share their data. There will also be an online media exhibition space where students can share projects they created in different courses.

Such tools can encourage student agency, facilitate customization of education to each student's interests and provide useful data for assessment and evolution of curricula. In the context of our digital culture curriculum, we will use these tools to search for simple trends (popular courses, popular paths etc.) as well as complex ones (which courses cover particular proficiencies well, which courses produce most unexpected and entrepreneurial outcomes etc.) and use the results for continuous improvement. The fast evolution of contemporary grand challenge areas and the active engagement of students in the structuring of their education will promote emergent structures and continuous change. Contemporary liberal education must evolve continuously in order to remain consequential.

Post-disciplinary assessment and evaluation structures

Assessment structures for a post-disciplinary liberal education curriculum must be in keeping with the key design principles of such a curriculum [2, 18]. The focus should be on whether the curriculum is training problem solvers and whether these problem solvers are having an impact on society. We have not yet implemented our planned assessment structures for digital culture so I will not discuss these in detail. However, we have implemented some significant changes in the way we evaluate faculty at the School of Arts, Media and Engineering so as to encourage inter/transdisciplinary processes and outcomes. I discuss our evaluation and promotion and tenure criteria in detail in a recent publication [19]. In closing this talk I want to briefly highlight three elements from these criteria that I believe can scale well to the evaluation of students, faculty and learning outcomes of post-disciplinary liberal education.

i) Calibrating evaluation matrices across a diverse set of outcomes and practices

Post-disciplinary work in grand challenge areas produces a broad range of outcomes. To facilitate evaluation, it is important to develop a meta-matrix that can help calibrate assessment of different outcomes in a quantifiable manner. For example, work at AME bridges engineering, sciences and the arts. Outcomes range from high impact journal publications, to software and hardware systems, fieldwork in schools and communities, and performances. To promote a calibrated evaluation of projects, and of faculty and students working on the projects, we produced a hierarchy of four outcome categories: major, standard, minor and supportive. All participating disciplines were asked to provide some form of quantitative criteria for ranking all possible research and creative activity outcomes of their discipline into these categories. These criteria were then combined into unified guidelines for classification of all AME outcomes. The creation of this meta-disciplinary measurement system allows AME to set expectations in terms of numbers of outcomes per category per evaluation time frame. For example: a well-supported research team at AME is expected to produce at least 2 major and 2 standard outcomes per year. Each of the four outcomes however can be very different. Evaluators not familiar with a particular type of outcome (i.e. an engineering faculty member might not be familiar with the impact of an installation at the Exploratorium in San Francisco) can develop an appreciation of the significance of that outcome through its meta-ranking as major, standard or minor. An evaluator not familiar with the area of activity of an AME faculty member (i.e. a psychology faculty may not be familiar with media engineering journals and conferences) can still approach the record of that faculty member in terms of the number of major or standard products he has produced and compare that record to the records of other AME faculty.

ii) Expanding the notion of "gatekeeper" and "impact"

Post-disciplinary work that aims to solve real-world grand challenges cannot be evaluated solely by academic criteria or academic experts. Furthermore, assessment should not solely focus on seminal pieces of standalone work. Insights from real world stakeholders and measuring of impact in terms of improving daily life must be integrated in the evaluation process. For example, the AME criteria allow for an embedded media system or methodology to be treated as a research outcome in its own right and be categorized as a major, standard or minor research product based on two indicative embeddedness criteria: a) the level of product adoption by the relevant communities (i.e. how many teachers in K-12 schools use the system to deliver curriculum; how many students are taught) and b) the level of documented improvement in daily life of relevant subject groups (i.e. a considerable number of stroke survivors are using the system to enhance their daily rehabilitation routine). Similarly, a very popular blog that enhances societal reflection on sustainability could also be considered a major or standard product.

iii) Rethinking authoring conventions.
Team authorship in post-disciplinary work cannot always be handled through traditional authoring conventions. Therefore AME criteria include two approaches to listing authors. If the contributions of the main authors are clearly gradated, then traditional author listing must be used (1st author, 2nd author etc). If the contributions of main authors are of equal effort and significance, then group authoring must be used. In group authoring, all lead authors are listed as primary authors and the remaining authors as either secondary or contributing authors.

iv) Integrating individual and team evaluation processes
Post-disciplinary experts need to be good individual members of successful teams. Being weak members of good teams, or great individual members of unsuccessful teams, or just great individuals that cannot work in teams is not adequate. The evaluation of post-disciplinary students and faculty necessitates methods that assess an individual in the context of a team. For example, the AME criteria assign 20% of the weight of a faculty or student evaluation to interdisciplinary connectivity: the ability of a member of AME to successfully collaborate with their colleagues and bridge different perspectives. We can measure the strength of the connection between any two members of the AME community based on the number of collaborative research outcomes these two members have jointly worked on. We can measure each member's network in terms of size (number of connections), strength of connections, repeat and new connections and interdisciplinary make-up of connections. We can also review the number of authors per research product and the number of disciplines per research product of a member.

Using all above strategies it is possible to perform a post-disciplinary evaluation of a team or individual. How many major or standard products as a primary author does an individual have? How diverse are those outcomes? How many of the outcomes of a research team are strongly embedded in the real world and adopted by practitioners? How strong, inclusive and balanced is the network of a team?

Conclusion

Post-disciplinary liberal education is a highly fitted preparation for the complex world of the 21st century. It is also a very exciting challenge for the academic community. I appreciate the opportunity to participate in this workshop on engineering and liberal education and be able to share thoughts and insights with so many distinguished colleagues active in this area. Thank you for your time.

Acknowledgments

The graphics for this presentation were developed by Aisling Kelliher. Figure 6 was compiled by Nicole Lehrer. The developers of the mixed reality rehabilitation system are listed on the project site (http://ame2.asu.edu/projects/mrrehab/). The faculty developing the digital culture curriculum are listed at (http://herbergerinstitute.asu.edu/degrees/digital_culture).

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Part II: Summary of Participant Discussions in Response to Keynote Address

Table 1
Recorder: Mark Wunderlich, Visiting Assistant Professor of Philosophy, Union

Richard Miller notes that the new engineering challenges the world faces will require a holistic, systems approach to intentional engineering design that embraces the need to include human behavior on a global scale. How can we educate students, both in engineering and the liberal arts, to not just solve the specific problems given to them, but instead to respond to the demands and consequences of human activity?

Modified question: How can we get students to think seriously about the demands and consequences of human activity, as opposed to focusing narrowly on specific problems that are given to them?

A significant contributor to how students understand engineering problems is how they are socialized as engineers. Thinking of approaches as engineering approaches, rather than identifying themselves exclusively as engineers, can help students to embrace a broader understanding of the problems they face.

Experiences outside the classroom can provide perspective. For example, students can both observe and participate in off-campus community projects. When they are exposed to projects in the field, students should confront the variety of approaches that were considered when pursuing each project.

Some experiences in the classroom can be particularly helpful. Students can be exposed to contextualized historical examples. Case studies can be helpful, especially studies in how problems grow out of solutions to previous problems. Instructors can invite guest lecturers from a variety of departments, though they should take care to avoid partitioning material into an engineering part and a non-engineering part. In addition, instructors may consider creating a course on unintended consequences; such a course could include a wide range of engaging historical examples.

Students can be encouraged to pursue open-ended design projects. Helping to define an engineering problem can give students a broader perspective. Competitions can be stimulating, especially with carefully crafted scoring (artificially defined metrics for scoring can be problematic). `Coopetition', in which the scoring system rewards collaboration with competitors, can help students to avoid narrow understandings of the engineering problems they face. Similarly, interdisciplinary grand challenges can be very fruitful.

Table 2
Recorder: Cherrice Traver, Dean of Engineering, Union

Richard Miller observes that leaders will require a much greater level of understanding of the non-technical issues surrounding technological invention in order to achieve the desired outcomes and avoid unintended consequences. How can members of the engineering profession, working together with others, respond to, and perhaps anticipate, the unintended consequences of previous and current technologies?

We first discussed our desire to modify the question to replace “unintended” with “unanticipated”. “Unanticipated” is a more appropriately neutral word, and is descriptive rather than normative. While “unintended” presumes a negative result from good intentions, there are many examples (lasers resulted in compact disk players) where the unintended is positive. Also “unanticipated” is broader than “unintended”. When one approaches a problem, one anticipates based on knowledge. Anytime we consider a complex problem, we need to consider our lack of knowledge. This implies considering unanticipated consequences.

Next we considered the answer to the question. Unanticipated consequences imply that there was “unknown space” during the design process. By bringing more voices to the table, and give them equal weight, then more of the space can be known. Every dimension is important.

In the educational process, it is important for students to understand that every dimension is important. Case studies were introduced as a way to do this. Case study examples should have inputs from ethics, history, etc., where those perspectives are keys to solving problems.

We then discussed different levels (undergraduate, graduate), scholars vs. students, and then global vs. local.

Example from Wellesley course:

Case studies could be critical decisions in medical technology. The idea is to focus on real people – genetic counselors, natural fusion, outcomes are life quality – attempt to show how statistics, ethics, and other dimensions are very important. Organically interdisciplinary. Team taught, model discourse and acquiring knowledge. Few if any pre-requisites. Motivates studying.

Another example at Wellesley is their introduction to engineering course. The view of how mathematics is used in real world problems is empowering.

In the curriculum overall, there needs to be a balance in all years of study between interdisciplinary, real-world examples and disciplinary education. This requires enlightened advising. There are some things that naturally need to be learned before others.

Our “final answer”:

Teams of faculty should develop real life case studies that naturally integrate different disciplinary perspectives. The case studies should clearly illustrate how multiple perspectives are equally important in the solution of the problem, or conversely, how ignoring a perspective can result in less than satisfactory solutions to problems. The case studies should be introduced early in the first year so that students develop the attitude of appreciating the richness of complex problems, to motivate depth of study in their chosen discipline, and to inform their class choices. If students keep the attitude, develop disciplinary skills, and have more opportunities to practice on multi-disciplinary teams, then they will become team members with the skills to increase the number of consequences that are anticipated in the solutions to those problems.

Table 3
Recorder: Anastasia Pease, Visiting Assistant Professor, American Literature, Union

Both speakers recognize the parallel between educational paradigms in studio art and in project-based learning in engineering. How can this be exploited in the classroom?

- Explore the nature of the project –- start with product design. Engage the students in project-based, hands-on learning.
- MFA faculty can (and do) teach product design, with aesthetics playing a role in the functional aspects of the product.
- Arts’ feedback and evaluation formats can be applied to engineering projects: art critique/debate/thesis defense/performing arts model (body language, rhetoric, effective PowerPoint skills).
- Video-taping and critiquing student presentations help students develop better

communication skills, which are invaluable in the "real world."

- Art is about ways of seeing. Seeing and conceptualizing are a large part of engineering. Explore physical seeing vs. vision vs. interpreting the stimuli. Incorporate that knowledge into engineering projects.

Both keynote speakers observe that the complex problems of the 21st century transcend disciplinary preparation and practice. How can large, complex problems facilitate interdisciplinary cooperation between engineering and the liberal arts? What does problem based learning/complex problem based education mean for the liberal arts?

- Utilize industry connections and developing team-work skills: Dartmouth teams – for the capstone for the major students get "matched" with experts from other fields. Projects come from industry. Teams have to solve interpersonal as well as technical and design issues to complete the project.
- Involve students in groups of different majors on project-oriented terms abroad. E.g. Union College's third-world water supply project: engineers and non-engineers work together to create a sustainable solution to a complex problem in a small third-world village.
- Help students pursue their own passion, e.g. for sustainability. (Projects do not have to be for college credit. But individual courses can be designed around students' interests.)
- For example: the "Big Green Bus" at Dartmouth started as a quasi – engineering project, with many students involved. It was not a deliberately designed interdisciplinary experience, yet it was empowering and useful for many engineers and non-engineers.

Table 4
Recorder: Stephen Kalista, Visiting Assistant Professor, Union

Richard Miller notes that the new engineering challenges the world faces will require a holistic, systems approach to intentional engineering design that embraces the need to include human behavior on a global scale. How can we educate students, both in engineering and the liberal arts, to not just solve the specific problems given to them, but instead to respond to the demands and consequences of human activity?
Both keynote speakers observe that the complex problems of the 21st century transcend disciplinary preparation and practice. How can large, complex problems facilitate interdisciplinary cooperation between engineering and the liberal arts? What does problem based learning/complex problem based education mean for the liberal arts?

Rather than directly addressing the questions, the table's discussion ran the gamut from a discussion of concerns with the current system, recognition of some of the technical challenges that face our world, and ultimately focused on ways to educate and prepare engineering students to tackle these issues as contributors to society. In the end, the group felt that our students would benefit from an educational philosophy which, from the start would encourage creativity, raise student expectations of their own capability to solve big-picture problems, and finally bestow on them an expectation that they are leaders in the path forward. The following will highlight those discussions and relevant conclusions.

Initially, the group expressed its concern that the goals of a broad-based engineering education are beholden to the requirements of ABET. The group struggled with the notion that our ability to train a more liberally educated engineer might be inhibited by stringent ABET requirements. The traditional approach of engineering education over the last ~100 years has been based on the research university model not a classical, liberal model, therefore a serious effort by groups such as those at this conference is needed to help shape the future of engineering education to broaden the capabilities of our students to engage more far-reaching problems than the more defined ones they are trained to handle.

Beyond the current state of student training, the group also expressed concerns about the philosophy of engineering education and student recruitment. It was suggested that oftentimes the students we see in the classroom end up there because they were told in high school that they should pursue engineering because they had a particular prowess in mathematics. Conversely, students who seemed to favor the creative side are often discouraged from engineering and pushed towards the arts/humanities. Further, few are those whose creative bents survive the stringent and regimented engineering programs often encountered in the traditional system. Therefore, we need to look at the student recruitment process (so that we do not turn away potentially great engineers) and should design challenges to help bring out and encourage these creative skills in the students we do have, whether through other courses, novel course experiences, design projects, etc.

Additionally, several were concerned that our students can often go through the mechanics of solving a problem given to them; however, they often have trouble actually identifying the problems they are not given. To help solve some of the big problems facing the world now and in the future, our students must first be able to identify these problems and then understand the larger issues that arise in the various solutions they might propose (e.g. cultural, environmental, otherwise). Some of the group proposed condensing the traditional engineering curriculum to make space for new major courses or transdisciplinary experiences that would broaden student understanding to better equip them for these challenges. While there may not be an easy answer for how we do this, we should always be aware as educators and it should help guide our philosophy in our student interactions and in preparing our courses.

During the next portion of the discussion, the group examined some technical and other problems facing the world today and how engineers and engineering students might be positioned to help solve these problems. After all, engineers are, by nature, meant to be problem-solvers. Yet, while we hope to train them to see the big picture, they oftentimes are not equipped to truly identify problems and help provide solutions which address global issues beyond their training. As a faculty, we are leaders in helping shape student expectations, goals, and experience and have a significant role in shaping and framing their own philosophies on the engineering profession. Therefore, the group discussed some solutions based on how a shift in philosophical approach to engineering education might benefit the students and better establish their role in society.

Initially, the group discussed some current problems facing our world. A couple current examples were given including the war in Afghanistan and the BP oil spill in the Gulf. One participant noted that a recent panel reviewing the progress in Afghanistan had noted some tremendous resources and infrastructure being implemented, from healthcare facilities to schools; however the qualified individuals necessary to run these facilities were missing. This suggested that while there were some good solutions implemented, there was no one truly in charge of the big picture. Another mentioned the concerns that crucial decisions by those at BP or its partners in the drilling operation may have made decisions based on $'s rather than science or safety. While we do not know the precise circumstances or whether engineers had a deciding role in the chain of events leading up to the disaster, the outcome seems an example of how those leading us may not be technically equipped for the decisions they make and suggests those technically trained among us to step up to more important leadership positions. With advances in technology, there is clearly a demand for engineers to take leadership roles in our society which may not typically be given to them. This is not only true in the corporate world but as shareholders in government and policy leadership. Further, this is especially important in the increasingly complex global society in which societal challenges are becoming more and more technical in nature. Yet, the traditional leaders, policy shapers, and decision makers in our world come from other disciplines with little or no technical training.

As such, it seems important that train our students broadly and place them along a trajectory and with the expectations that they will help make the big decisions that solve major issues. Because they are ultimately tasked as problem-solvers, this seems an obvious area where they might contribute. Yet, there was concern at our table that student expectations and even their own philosophy on the engineering profession falls quite short in this area. For example, if one went into a law school classroom on the first day and told the students present that they were the future leaders of this nation, they would no doubt agree, voicing their approval. If we addressed a throng of political scientists proclaiming they were going to help lead the nation, solving its many policy issues and concerns, they would be quite pleased pushing forward with their studies. If we told a group of medical students they would cure the world's diseases, they would be proud to face this task. Yet, many of us expressed concern that a similar proclamation to a class full of engineers, stating that they would lead our nation in solving some of the most complex challenges in energy, civil infrastructure, and many of the technical and nontechnical problems beyond would lead to the students cowering behind their desks or at least questioning whether this is why they chose engineering. Leadership seems a mantle too many engineering students seem uneasy accepting. Often, they do not even wish to write papers claiming their abhorrence to writing to be one of the very reasons they became engineers. We each agreed this was an important issue and wondered, how do we help our students take their place in society as problem solvers?

To that end, how do we reverse direction encouraging our students toward a more active and voluntary role in solving the problems that face our world in the 21st century? It was suggested that perhaps we need to shift the philosophy of engineering education and the student mindset to prepare them for such a reality. Often we find our students are able to step up their performance when we increase the expectations. So, perhaps, we raise the bar from day one in the classroom, defining their role in society as one of leadership in solving problems and raising expectations in a realm we may not typically expect of them. While this might not address some of the issues with training, perhaps simple changes in how we define their role would go a long way toward them buying into a greater role as problem solvers in society, shifting both our philosophies on training and their outlook on their chosen profession pushing themselves forward with expectations of what they are "supposed to do" with that training.

In sum, in the end it seemed from our discussion, at least, that the sentiment was one of philosophy. We should recruit students with broader interests than simply mathematics. From the outset we should encourage their creativity, facilitate interactions with a variety of disciplines, and instill in them an expectation that they will be leaders in solving the great problems facing the world today. While we may have difficulty reshaping the curriculum to accomplish these goals, we may at least start by challenging our students' expectations for their own profession as leaders, moving society forward in solving some of the larger, more complex and often technical problems that will face our society in the next 100 years.

Table 5

Recorder: Mike Hagerman, Associate Professor of Chemistry, Union

Thanassis Rikakis notes that we have to evaluate educational network structures and their impact. What has been done at your institution to improve structures and networks for the education of complex problem solvers?

- Blackboard site to share course materials and assessment strategies
- Show in the middle of campus to promote programs
- Website: Modules for team teaching (e.g. Water Systems in the Ancient World)
- Team teaching
- Cluster Gen Education program
- External Grants that support interdisciplinary programs (NSF, Mellon, …)
- Studies focusing on Sustainability (new majors @ Cal Poly and RPI)
- Center for Teaching and Learning (workshops, teaching groups, storytelling, travel money @ Univ of GA)
- Undergraduate Research Summer Seminars
- Faculty Learning Communities (Fairfield University)
- Students often lead interests (aerogels, nanoscience, environment, sustainability)
- Focus on areas where there is a perceived need
- Get rid of departmental structures (Olin College)
- Use student clubs to teach and inform
- Use Service Learning activities that promote teamwork and problem solving skills in group setting
- Attend National Meetings of Professional Societies and bring students

How can large, complex problems facilitate interdisciplinary cooperation between engineering and the liberal arts? What does problem based learning/complex problem based education mean for the liberal arts?

We did not get far on this question spending most of our time on Q1. We offer these insights:

- Complex problems require cross disciplinary perspectives and outcomes based activities
- Service learning that encourages college, university and community interfaces strengthens education opportunities
- Focus on environment and sustainability concerns
- Need a symposium on restructuring departmental and college structures to support bridging the gap between liberal arts and engineering
- Classical splits between disciplines and within disciplines for PhD work does always support these bridging activities

Table 6

Recorder: Janet Grigsby, Senior Lecturer in Sociology, Union

Both speakers recognize the parallel between educational paradigms in studio art and in project-based learning in engineering. How can this be exploited in the classroom?

After some discussion, the group concluded that the speakers did not really discuss studio art directly. Several members have had experience working with studio art classes and we discussed how lessons learned there might help make connections between engineering and liberal arts. The following points emerged:

- One participant had encountered Union's set-building studio in the theater department. He observed that in the theater set department, students became adept at making stuff, but do they know the science behind it? Engineering could help here.
- How studio art works: a stimulus, then create a project. But we asked, do they get the canon, if they only do projects? This is an issue that engineering deals with – whether project-based learning really gives students the content they need to go further.
- We asked: Is the classroom the problem? Is it a device that is just for convenience [of teacher, school, etc.] but not necessarily the best for learning?!
    - The same issue arises with why we have lecturers!
    - Now a commodity rather than anything else.
    - Do we need to teach the content??
    - Gathering together adds to what you are doing – in studio art classes, interaction is important
    - One participant had worked in projects where art students have to work in a medium with which they are unfamiliar but with which engineers are – engineers have to work with art students to do it. Engineers find they have to talk to artists about what their intention is in order to help them. This develops ability of students on both sides to communicate effectively across the divide.
    - At West point: A client interaction piece has been added to their capstone experience for engineers with very effective results.
- How did it get this way? Where did the divide between engineering and the liberal arts come from?
    - Goes back to sputnik and the 'scientizing' of engineering – and the overall ambivalent awe and disdain that American culture has for science.
    - Having the middle man in the real world of work exacerbates it – architect, urban planners.
    - Military – much responsibility given to Army Corps of Engineers.
    - There is also a big difference between engineering students and engineers – you learn 'it' [what you really need to know in the work place, doing engineering] quickly once you get out of school and enter the real world.
    - Doing it right is expensive – takes a lot of work, money – referring to experiences like the joint work between studio art classes and engineering students.
    - One participant who does this reports he gets lots of support.
    - But, do/would we all?? The rest of the group was not as certain they could get this support in their own institutions.

Problem with ABET: Are the ABET requirements an historical artifact? Might they also change?

- Why is there no professional degree in engineering as there is in law, medicine, or the other professions? – we did not come to a consensus on this.
- Engineers have to learn a set of languages – this is really what we teach in our various courses.
- We noted, but did not discuss in detail, that the speaker's discussion of branches was helpful.

Both keynote speakers observe that the complex problems of the 21st century transcend disciplinary preparation and practice. How can large, complex problems facilitate interdisciplinary cooperation between engineering and the liberal arts? What does problem based learning/complex problem based education mean for the liberal arts?

(Our discussion of this question was quite short, but some of the issues it raises we touched on for the first question.)

- We asked: Who should come to the table to discuss these issues? Consensus seemed to be that it should not just be engineers, but we were not clear who should be included.
- Our last minute or two raised the issue that there is a tremendous among of arrogance in engineering which gets in the way of making progress.
- (Time up, further discussion of this last important point deferred to further sessions!)

Table 7

Recorder: Ashraf Ghaly, Professor of Engineering, Union

Richard Miller notes that the new engineering challenges the world faces will require a holistic, systems approach to intentional engineering design that embraces the need to include human behavior on a global scale. How can we educate students, both in engineering and the liberal arts, to not just solve the specific problems given to them, but instead to respond to the demands and consequences of human activity?

- Frame the questions as "grand challenges" facing society. This will energize the students and encourages them to find answers.
- Students need motivating factors to feel strongly about the issues under consideration.
- Faculty should not teach their students to solve a specific problem, rather to think broadly and consider all factors impacting various solutions.
- It is important to realize that technology has become an integral part of society and "traditional" liberal arts void of technology may be no longer critical.
- Non-engineering students may be intimidated by technology and may also feel they lack the background to take technology courses. This feeling should be dealt with.
- Technology is a natural extension to science. Start with technology in the classroom and students will realize that it is interwoven in their daily lives.
- Use models that speak to students without getting too deep into the theory. Use conceptual models and address the question of how or why something works.
- We must reject the "Utopian gloss" that we put on problems, and we should strive to make these problems realistic in addressing societal needs.
- Use case studies to discuss social, political, and economical aspects affecting engineering issues.

Table 8

Recorder: Mary Carroll, Professor and Chair of Chemistry, Union

Richard Miller observes that leaders will require a much greater level of understanding of the non-technical issues surrounding technological invention in order to achieve the desired outcomes and avoid unintended consequences. How can members of the engineering profession, working together with others, respond to, and perhaps anticipate, the unintended consequences of previous and current technologies?

Both keynote speakers observe that the complex problems of the 21st century transcend disciplinary preparation and practice. How can large, complex problems facilitate interdisciplinary cooperation between engineering and the liberal arts? What does problem based learning/complex problem based education mean for the liberal arts?

A lively and free-ranging discussion ensued, a sampling of which is captured below:

Would our colleagues in humanities agree with the premise that a goal of higher education is to educate students to solve problems? Should we be focused on having students frame problems or solve problems? Indeed, what is meant by the word ‘problem’ varies by discipline. And there are problems that cannot be addressed by design. What does it mean to understand? Is there a common language that can be used for these discussions? How do we teach students to create knowledge? Do we focus on developing skills and knowledge or on creating an environment in which students can do so? What is the intrinsic motivation of the student? Do we have, and teach, respect for the culture of each discipline? Does approaching complex problems help students to recognize different ways of thinking or sense-making? Working outside of the ‘comfort zone’ of the individual areas of faculty expertise can be perceived as risky. To what extent are we asking our students to do something that we ourselves struggle to achieve?

The members of the group concluded that articulating the real differences that exist between academic disciplines in engineering and the liberal arts gets in the way of interdisciplinary cooperation. And we noted that the questions were framed from an engineering perspective. Consequently, we attempted to rewrite the questions to be more inclusive, as follows:

(1) How can ~~members of the engineering profession~~ **we**, working together ~~with others~~, respond to, and perhaps anticipate, the ~~unintended~~ **unanticipated** consequences of previous and current technologies?

(2) How can large, complex problems facilitate ~~interdisciplinary~~ cooperation ~~between engineering and the liberal arts~~? What does problem based learning/complex problem based education mean for the liberal arts?

But we did not have time to formulate an answer to either question.

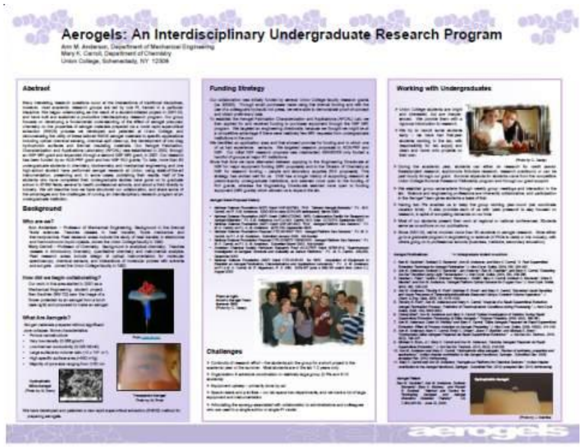
Table 9
Recorder: Ann Anderson, Professor of Mechanical Engineering, Union

Thanassis Rikakis notes that we have to evaluate educational network structures and their impact. What has been done at your institution to improve structures and networks for the education of complex problem solvers?

The participants first discussed the question "are disciplines more or less isolated these days" and thought that current budgeting and administrative structures often get in the way of bringing disciplines together. Many of us were concerned that institutions have evolved such that it is easier to make things happen if they fit into a predefined pigeon hole (i.e. governance structures need to change if we want interdisciplinary programs to succeed). We then went on to discuss ways to address this problem. We discussed successful endeavors to develop cross disciplinary structures that involved seed money or outside funding (from places like Mellon), ground up (not top down) support for change, good leadership from the top and the use of problem based learning. We also talked about and recommend the use of faculty clubs (informal meals) or scholarship centers (informal talks) as good places to get faculty from different disciplines together more often.

Part III: Poster Session: Examples of Integration

Full-sized pdf files of the posters are available in the electronic version of these Proceedings, and at the Symposium web site: www.union.edu/integration



Aerogels: An Interdisciplinary Undergraduate Research Program

Ann M. Anderson, Department of Mechanical Engineering
Mary K. Carroll, Department of Chemistry
Union College, Schenectady, NY 12308

Abstract

Funding Strategy

Working with Undergraduates

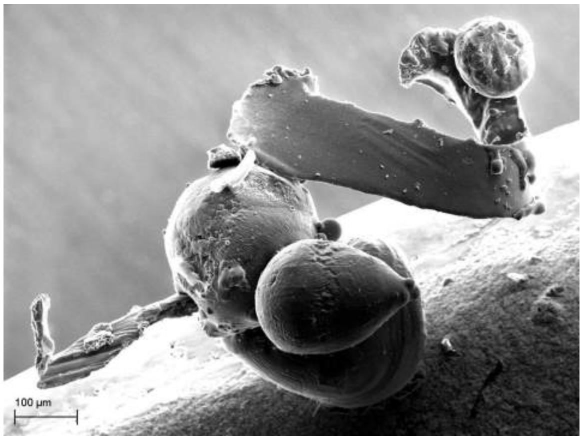
Background

Challenges

Aerogels: An Interdisciplinary Undergraduate Research Program

Ann M. Anderson, Dept. of Mechanical Engineering; and Mary K. Carroll, Dept. of Chemistry, Union College

Many interesting research questions occur at the intersections of traditional disciplines; however, most academic research groups are led by one PI, trained in a particular discipline. We began collaborating as the result of a student-initiated project in 2001-02, and have built and sustained a productive interdisciplinary research program. Our group focuses on developing a fundamental understanding of the effect of aerogel precursor chemistry on the properties of aerogel materials prepared via a novel rapid supercritical extraction (RSCE) process we developed and patented at Union College, and demonstrating the utility of these tailored RSCE aerogel materials to specific applications including optical chemical sensing, chemical spill clean-up, the development of low drag hydrophobic surfaces and thermal insulating materials. Our Aerogel Fabrication, Characterization and Applications Laboratory (AFCAL) was established in 2002, through an NSF MRI grant and expanded through a second NSF MRI grant, in 2007. Our research has been funded by an ACS-PRF grant and two NSF RUI grants. To date, more than 50 undergraduate students in chemistry, biochemistry and mechanical engineering and one high-school student have performed aerogel research at Union, using state-of-the-art instrumentation, presenting and, in some cases, publishing their results. Half of the students who have completed their undergraduate studies have gone on to graduate school in STEM fields, several to health professional schools, and about a third directly to industry. We will describe how we have structured our collaboration, and share some of the advantages and the challenges of running an interdisciplinary research program at an undergraduate institution.



Bringing scanning electron microscopy to undergraduate students through an art-nanoscience collaboration

Kevin E. Bubriski, Dept. of Visual Arts; Palmyra E. Catravas, Dept. of Electrical and Computer Engineering; Brian D. Cohen, Dept. of Biology; Michael E. Hagerman, Dept. of Chemistry; Mark Hooker, Bioengineering Program; Samuel Amanual and Seyfollah Maleki, Dept. of Physics and Astronomy; and Rebecca Cortez, Dept. of Mechanical Engineering; Union College

We will describe a novel capstone project bringing together undergraduate students from visual arts and nanotechnology to collaborate on an art-nanoscience exhibition. Students from the nanotechnology course bring to the collaboration an understanding of scanning electron microscopy imaging technique and sample preparation acquired through weekly hands-on laboratories with the instrument. Students from the photography course bring experience on image composition and aesthetics to the table, and share these insights with the nano students. The students work together to image materials both directly related to the nanotechnology course, such as carbon nanotubes, electrospun fibers and clay nanocomposites with embedded quantum dots, as well as samples from everyday life (bees, sandpaper, etc.). This project is currently bringing together thirty-three students from a wide range of majors that span engineering and the liberal arts: Chemistry, Biology, Mechanical Engineering, Electrical and Computer Engineering, Bioengineering, Psychology, Neuroscience, Sociology/Social Sciences, History and Visual Arts.

Terrascope Youth Radio: A University-Community Partnership
Engaging Urban Teens and Undergraduate Engineering Students

Terrascope Youth Radio: A university-community partnership engaging urban teens and undergraduate engineering students

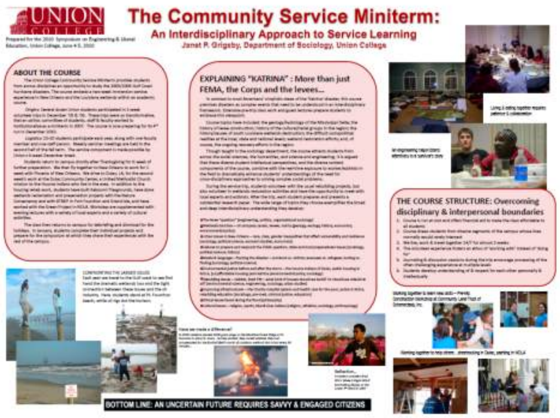
Ari W. Epstein, Terrascope Program and Dept. of Civil and Environmental Engineering, MIT; Beverly Mire, Cambridge Youth Programs; Trent Ramsey, Cambridge Youth Programs; Karen Gareis, Goodman Research Group; Emily Davidson, undergraduate, MIT; Elizabeth Jones, undergraduate, MIT; Michelle Slosberg, undergraduate, MIT; and Rafael Bras, Henry Samueli School of Engineering, University of California, Irvine

Terrascope Youth Radio is an NSF-funded partnership between MIT and the City of Cambridge Youth Programs, in which undergraduate engineering students mentor local urban teens as the teens produce radio/audio programming on environmental topics. The interaction has been remarkably fruitful, both for the teens and for the undergraduates. The undergraduates play strong roles in shaping the program, developing curriculum, and in day-to-day operations, along with their mentoring work. They acquire teaching experience in an intensive but collegial setting, and they have the opportunity to relate their own developing skills and outlook to high-school students who may come from very different backgrounds. The teens relate easily to the MIT students, and through them develop a sense of comfort working regularly in the technically-oriented MIT setting. They also develop strong skills in understanding and reporting scientific/technical stories, and in relating those stories to their own lives.

Adapting Engineering for a Non-Engineering Audience Using Common Liberal Arts Features

Ashraf Ghaly, Ph.D., P.E., Dept. of Engineering, Union College

The integration of engineering and the liberal arts has been a subject of interest for a long time. It might be useful to first appreciate the ways in which engineering and the liberal arts differ to make them an easier target for integration. Engineering differentiates from the liberal arts in some fundamental ways. First and foremost, it is intimately related to the welfare of society and safety of the public, thus it cannot be open for interpretation. Engineered systems are expected to work, work well, and perform the function they are designed for. Second, engineering is a profession that requires certain technical knowledge and a minimum degree of specialization. The contemporary liberal arts comprise the study of literature, languages, philosophy, history, mathematics, and science. Some areas of commonality, such as mathematics and science, exist between engineering and the liberal arts, which could be used as grounds for integration for the mutual benefit of both. A course entitled "Construction for Humanity" has been developed in which rich content of "illustrated engineering" was used to help students visualize engineering principles that are otherwise uneasy to comprehend or appreciate. The course was offered in a context of history of construction, a survey of the architectural literature, and a review of engineering milestones throughout history. This course addresses the human need for shelter and the evolution of construction from building simple huts and earth walls to present day sophisticated and highly functional structures. The blend of history and engineering, and the study of the impact of social, cultural, political, economical, environmental, climatic, and religious factors on the shape, type, size, and function of the built structure were a successful recipe that fascinated the students. The assigned readings and the required biweekly papers were another source of excitement for the students in this course. Assigned readings, together with class presentations demonstrated complex principles in an easy to understand fashion with strong visual content. The required biweekly papers left it open to the students to select subjects within predefined themes with no geographic limitation. They were told "the world is your platform" and this made it wide open for exploration of all topics of interest. The seamless merging of engineering and the liberal arts that this course achieved did not only add to students' appreciation of technical principles but also increased their capabilities of rational thinking, which is what they need to be successful citizens in today's highly technological society.



The Community Service Miniterm:

An Interdisciplinary Approach to Service Learning

Janet P. Grigsby, Department of Sociology, Union College

ABOUT THE COURSE

EXPLAINING "KATRINA" : More than just FEMA, the Corps and the levees…

THE COURSE STRUCTURE: Overcoming disciplinary & interpersonal boundaries

BOTTOM LINE: AN UNCERTAIN FUTURE REQUIRES SAVVY & ENGAGED CITIZENS

The Community Service Miniterm: An Interdisciplinary Approach to Service Learning

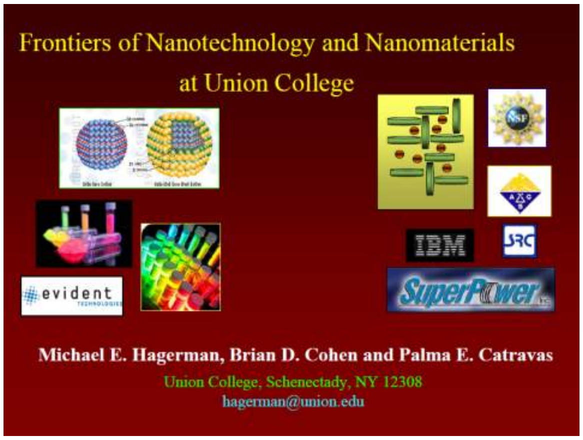
Janet P. Grigsby, Ph.D., Senior Lecturer in Sociology, Union College

The Union College Community Service Miniterm provides students from across disciplines an opportunity to study the 2005/2008 Gulf Coast hurricane disasters. The course embeds a two-week immersion service experience in New Orleans and the Louisiana wetlands within an academic course.

In contrast to most Americans' simplistic views of the 'Katrina' disaster, this course premises disasters as complex events that need to be understood in an interdisciplinary framework. Extensive pre-trip class work and guest lectures prepare students to embrace this viewpoint. Topics have included: the geology/hydrology of the Mississippi Delta; the history of levee construction; history of the cultural/racial groups in the region; the history/causes of south Louisiana wetlands destruction; the difficult sociopolitical realities at the local, state and national levels; wetland restoration efforts; and, of course, the ongoing recovery efforts in the region.

During the service trip, students volunteer with the usual rebuilding projects, but also volunteer in wetlands restoration activities and have the opportunity to meet with local experts and activists. After the trip, each student prepares and presents a substantial research paper.

Though taught in the sociology department, the course attracts students from across the social sciences, the humanities, and science and engineering. It is argued that these diverse student intellectual perspectives, and the diverse content components of the course, combine with the real-time exposure to worker/activists in the field to dramatically enhance students' understandings of the need for cross-disciplinary approaches to solving complex social problems.



Frontiers of Nanotechnology and Nanomaterials
at Union College

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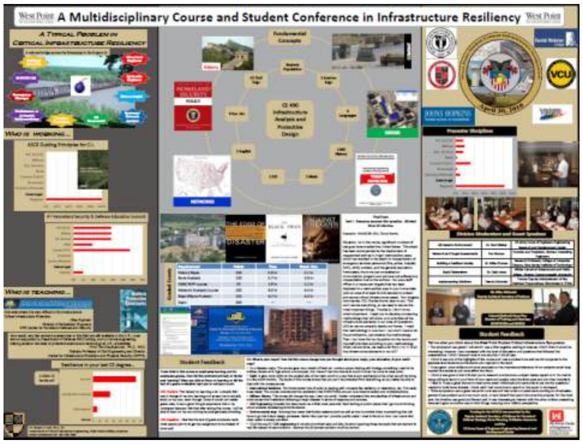
Frontiers of Nanotechnology and Nanomaterials at Union College

Michael E. Hagerman, Dept. of Chemistry; Brian D. Cohen, Dept. of Biology; and Palmyra E. Catravas, Dept. of Electrical and Computer Engineering, Union College

We have developed an undergraduate course cross-listed in chemistry and engineering that has exposed our students to optical, scanning probe and electron microscopy, bottom-up versus top-down approaches to materials fabrication including electrospinning and solution phase self-assembly, and fundamental properties of nanomaterials with key emphases on semiconductor quantum dots, polymers, inorganic-organic nanocomposites, and NEMS. New nanoscience laboratories and innovative course materials will be discussed along with successes with invited speakers and oral and written assignments that have led to three student coauthored publications. This course is integral to our nanotechnology minor and is part of our college-wide, cross disciplinary initiative entitled Converging Technologies. A central success of the course has been the strengthening of partnerships with local industrial and academic institutions in New York's Tech Valley, including IBM, Global Foundries, GE Global Research, Evident Technologies, RPI and Albany NanoTech. The authors gratefully acknowledge financial support from the National Science Foundation.



A Multidisciplinary Course and Student Conference in Infrastructure Resiliency

A TYPICAL PROBLEM IN CRITICAL INFRASTRUCTURE RESILIENCY

WHO IS WORKING...

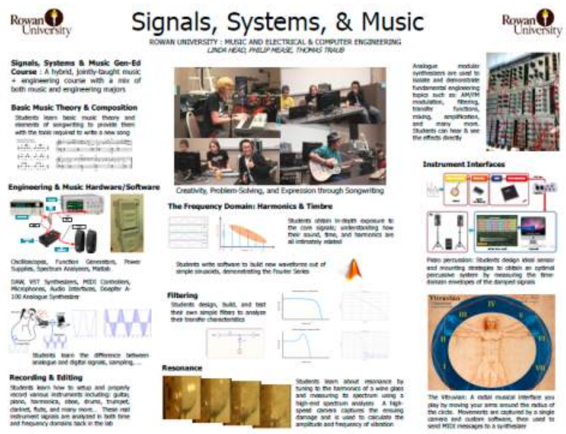
WHO IS TEACHING...

Student Feedback

A Multidisciplinary Course and Student Conference in Infrastructure Resiliency

Steven D. Hart, Ph.D., P.E., Lieutenant Colonel, United States Army Corps of Engineers, United States Military Academy

The resiliency of our nation's critical infrastructures is a topic of interest at the local, regional, and national levels. In spite of the fact that this field is inherently multi-disciplinary, many academic and professional endeavors remain insular. The American Society of Civil Engineers recently published *Guiding Principles for the Nation's Critical Infrastructure*; all members of the task committee were civil engineers. The *Homeland Security Affairs Journal* recently published "Resilience: The Grand Strategy" by Philip J. Palin; none of the 36 references were engineering sources. This presentation explains the outcomes of a multidisciplinary course in Infrastructure Analysis and Protective Design taught at the United States Military Academy in Spring, 2010. Of the 38 students, 254 were civil and environmental engineers and 13 were liberal arts majors. Students were encouraged to approach all topics in the course from the perspective of their major while striving to understand new viewpoints. The principle learning activity was a course project which was presented at the West Point Student Critical Infrastructure Symposium that included 11 students from around the country representing a variety of academic and professional disciplines. Student perceptions of and contributions to course topics were assessed to determine how different majors approached issues and addressed problems. Beginning of course and end of course surveys were used to determine if these perceptions changed during the course. Finally, student understanding of the importance disciplinary cooperation in achieving technologically sound, economically viable, and politically feasible solutions was assessed.



Signals, Systems, & Music

ROWAN UNIVERSITY : MUSIC AND ELECTRICAL & COMPUTER ENGINEERING

LINDA HEAD, PHILIP MEASE, THOMAS TRAUB

Signals, Systems & Music Gen-Ed Course : A hybrid, jointly-taught music + engineering course with a mix of both music and engineering majors

Basic Music Theory & Composition

Students learn basic music theory and elements of songwriting to provide them with the tools required to write a new song

Engineering & Music Hardware/Software

Oscilloscopes, Function Generators, Power Supplies, Spectrum Analyzers, Matlab

DAW, VST Synthesizers, MIDI Controllers, Microphones, Audio Interfaces, Doepfer A-100 Analogue Synthesizer

Students learn the difference between analogue and digital signals, sampling, ...

Recording & Editing

Students learn how to setup and properly record various instruments including: guitar, piano, harmonica, oboe, drums, trumpet, clarinet, flute, and many more... These real instrument signals are analyzed in both time and frequency domains back in the lab

Creativity, Problem-Solving, and Expression through Songwriting

The Frequency Domain: Harmonics & Timbre

Students obtain in-depth exposure to the core signals; understanding how their sound, time, and harmonics are all intimately related

Students write software to build new waveforms out of simple sinusoids, demonstrating the Fourier Series

Filtering

Students design, build, and test their own simple filters to analyze their transfer characteristics

Resonance

Students learn about resonance by tuning to the harmonics of a wine glass and measuring its spectrum using a high-end spectrum analyzer. A high-speed camera captures the ensuing damage and is used to calculate the amplitude and frequency of vibration

Analogue modular synthesizers are used to isolate and demonstrate fundamental engineering topics such as AM/FM modulation, filtering, transfer functions, mixing, amplification, and many more. Students can hear & see the effects directly

Instrument Interfaces

Piezo percussion: Students design ideal sensor and mounting strategies to obtain an optimal percussive system by measuring the time-domain envelopes of the damped signals

The Vitruvian: A radial musical interface you play by moving your arms around the radius of the circle. Movements are captured by a single camera and custom software, then used to send MIDI messages to a synthesizer

Signals, Systems and Music: A General Education "Experience"

Linda M. Head, Dept. of Electrical and Computer Engineering; Thomas Traub and Phillip Mease, Dept. of Music, Rowan University

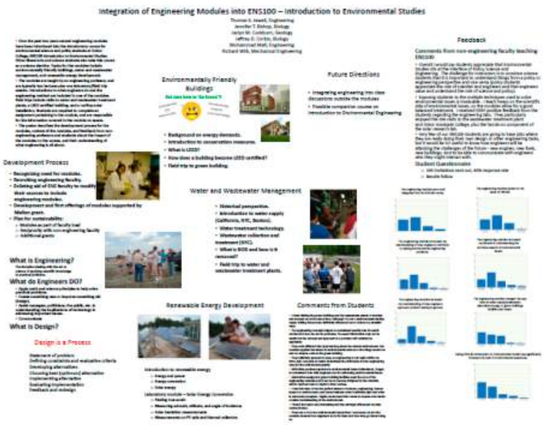
Rowan University's Electrical and Computer Engineering (ECE) and Music programs are collaborating on an electronic music composition course titled Signals, Systems and Music. This course is the first step in our efforts to develop a new concept for providing a general-education experience that transcends traditional disciplines. Our concept changes the focus of extradisciplinary courses from "exposure" to novel points of view to "immersion" in interdependent knowledge.

We are gathering music students and first-year engineering students for a novel educational experience: Music composition from an engineering systems point of view, exposing all students to concepts fundamental to both music and engineering, emphasizing the interconnectedness of the disciplines, and (hopefully) awakening the students' creativity. This course is presented as a general education experience that DOES NOT presume any background in music, mathematics or electronics.

We propose a presentation to the Symposium on Engineering and Liberal Education addressing the details of the first offering of this new course. We have developed:

- Lectures and exercises on music theory
- Lectures and exercises on principles of signals and systems appropriate to electronic music
- Laboratory experiences using both hardware and software

The course is co-taught by a professor from Music, a professor from ECE and a musician with experience in electronic music composition. We will present examples of all aspects of this course along with student final compositions. In addition, we will address future projects in our efforts to renew the general education experience at Rowan University.



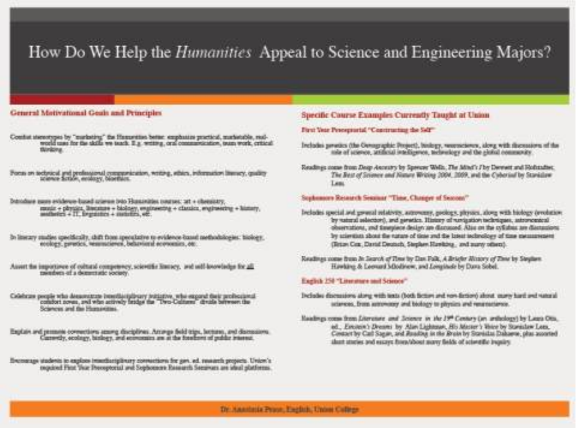
Integration of Engineering Modules into ENS100: Introduction to Environmental Studies

Thomas K. Jewell, Dept. of Engineering; Jeffrey Corbin and Jennifer Bishop, Dept. of Biology; Jaclyn Cockburn, Dept. of Geology; Richard Wilk, Dept. of Mechanical Engineering; and Mohammad Mafi, Dept. of Engineering, Union College

Over the past two years several engineering modules have been introduced into the introductory course for environmental science and policy students, ENS100: Introduction to Environmental Studies at Union College. Other liberal arts and science students also take this course as a science elective. Topics for the modules include environmentally friendly buildings, water and wastewater management, and renewable energy development.

The modules are taught by an engineering professor, and are typically two lectures plus one laboratory/field trip session. An introduction to what engineers do, and the engineering method is included in one of the modules. Field trips include visits to water and wastewater treatment plants, a LEED certified building, and a rooftop solar installation. Students are required to complete an assignment pertaining to the module, and are responsible for the information covered in the module on exams.

The poster will describe the development process for the modules, content of the modules, and feedback from non-engineering professors and students about the impact of the modules on the course, and their understanding of what engineering is all about.



How Do We Help the *Humanities* Appeal to Science and Engineering Majors?

General Motivational Goals and Principles

Specific Course Examples Currently Taught at Union

First Year Preceptorial "Constructing the Self"

Sophomore Research Seminar "Time, Changer of Seasons"

English 250 "Literature and Science"

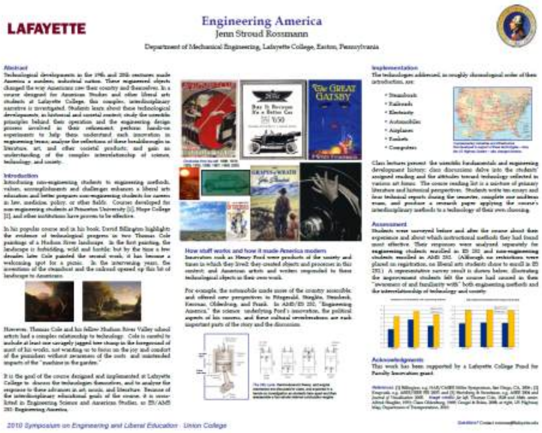
Dr. Anastasia Pease, English, Union College

How Do We Help the Humanities Appeal to Science and Engineering Majors?

Anastasia Pease, Dept. of English,
Union College

Many engineering and science majors dread the English general education requirements. Reading and writing about texts and literary theory seem a chore and a waste of time. Some of our own academic efforts are surely to blame for this problem. The extremely narrow specialization required for tenure prevents junior faculty from exploring other subjects. Literary theory in the last 30 years has made Literary Studies marginal to our culture. The field is now perceived by the general public as obtuse, self-important, vacuous, and impractical. How do we as Literature professors convince reluctant students that English classes are interesting and worthwhile?

As enthusiasts of reading and writing, we should use our celebrated communication skills to represent ourselves better. To put it bluntly, the Humanities should not sneer at better PR and better marketing. Humanities academics should never tire of stressing that the communication and analytical skills we teach are indispensible. However, in our technology-dominated world, PR alone won't solve our image problems, if we do not care enough to bridge the gap between ourselves and the sciences. I do not propose a forced, artificial bond between the Sciences and the Humanities. What I propose is an exploration of the areas where these two broad spheres already overlap: professional writing, ethics, science fiction, and the scientific study of literature. This presentation will focus on the ways that the required First-Year Preceptorials, Sophomore Research Seminars, and Literature classes can encompass the latest science, help students develop useful skills, and actually be enjoyable for science and engineering majors.



LAFAYETTE

Engineering America

Jenn Stroud Rossmann

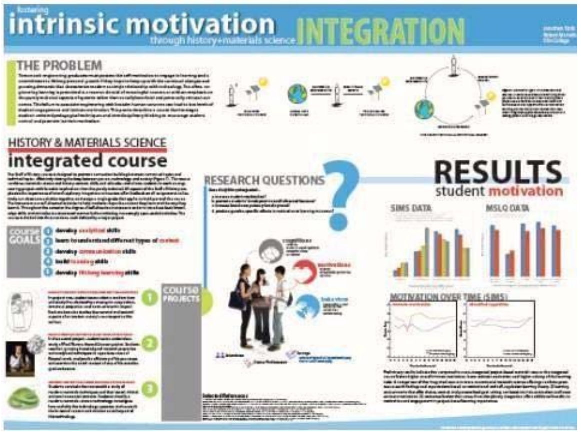
Department of Mechanical Engineering, Lafayette College, Easton, Pennsylvania

2010 Symposium on Engineering and Liberal Education · Union College

Engineering America

Jenn Stroud Rossmann, Dept. of Mechanical Engineering, Lafayette College

Technological developments helped America become a modern, industrial nation in the 19th and 20th centuries: the history of technology is a history of America. Innovators such as Henry Ford were products of the society and times in which they lived; they created objects and processes in this context; and American artists and writers responded to these technological objects in their own work. These engineered objects changed the way Americans saw their country and themselves. For example, the car made more of the country accessible; and offered new perspectives to Fitzgerald, Steinbeck, Kerouac, and Frank. In a course designed for American Studies and other liberal arts students at Lafayette College, this complex narrative is investigated. Students learn about these technological developments, in historical and societal context; study the scientific principles behind their operation and the engineering design process involved in their refinement; perform hands-on experiments to help them understand each innovation in engineering terms; analyze the reflections of these breakthroughs in literature, art, and other societal products; and gain an understanding of the complex interrelationship of science, technology, and society.



Fostering Intrinsic Motivation through History-Materials Science Integration

Jonathan Stolk and Robert Martello, Franklin W. Olin College of Engineering

Tomorrow's engineering graduates must possess the self-motivation to engage in learning and a commitment to lifelong personal growth if they hope to keep up with the continual changes and growing demands that characterize modern society's relationship with technology. Too often, engineering learning is presented in a manner devoid of meaningful context, or with an emphasis on the purely technical aspects of systems rather than socially beneficial and personally relevant outcomes. This failure to associate engineering with broader human concerns can lead to low levels of student engagement and intrinsic motivation. This poster describes a course that leverages student-centered pedagogical techniques and interdisciplinary thinking to encourage student control and promote intrinsic motivation. In "The 'Stuff' of History," a team-taught integrated course block, students build connections between materials science and historical analytical techniques as they complete a series of hands-on, self-directed projects. Historical and materials science content is tightly linked throughout the term, and all assignments emphasize connections between technical analyses and contextual factors such as environment, society, culture, economics, and politics. Investigation of student motivation using the Situational Motivation Scale and the Motivated Strategies for Learning Questionnaire indicates that the integrated course supports higher overall intrinsic motivation, lower extrinsic motivation, and higher valuing of the learning tasks compared to a non-integrated version of the materials science course. The findings from this investigation offer insights for STEM instructors wishing to design learning experiences that enable students to connect their technical studies with broader contextual considerations.

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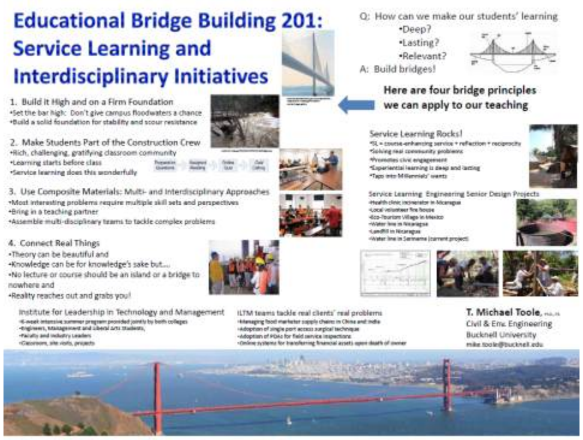

Educational Bridge Building 201: Service Learning and Interdisciplinary Initiatives

1. Build it High and on a Firm Foundation
- Set the bar high: Don't give campus floodwaters a chance
- Build a solid foundation for stability and scour resistance

2. Make Students Part of the Construction Crew
- Rich, challenging, gratifying classroom community
- Learning starts before class
- Service learning does this wonderfully

3. Use Composite Materials: Multi- and Interdisciplinary Approaches
- Most interesting problems require multiple skill sets and perspectives
- Bring in a teaching partner
- Assemble multi-disciplinary teams to tackle complex problems

4. Connect Real Things
- Theory can be beautiful and
- Knowledge can be for knowledge's sake but....
- No lecture or course should be an island or a bridge to nowhere and
- Reality reaches out and grabs you!

Q: How can we make our students' learning
- Deep?
- Lasting?
- Relevant?

A: Build bridges!

Here are four bridge principles we can apply to our teaching

Service Learning Rocks!
- SL = course-enhancing service + reflection + reciprocity
- Solving real community problems
- Promotes civic engagement
- Experiential learning is deep and lasting
- Taps into Millennials' wants

Service Learning Engineering Senior Design Projects
- Health clinic incinerator in Nicaragua
- Local volunteer fire house
- Eco-Tourism Village in Mexico
- Water line in Nicaragua
- Landfill in Nicaragua
- Water line in Suriname (current project)

Institute for Leadership in Technology and Management
- 6-week intensive summer program provided jointly by both colleges
- Engineers, Management and Liberal Arts Students,
- Faculty and Industry Leaders
- Classroom, site visits, projects

ILTM teams tackle real clients' real problems
- Managing food marketer supply chains in China and India
- Adoption of single port access surgical technique
- Adoption of PDAs for field service inspections
- Online systems for transferring financial assets upon death of owner

T. Michael Toole, PhD, PE
Civil & Env. Engineering
Bucknell University
mike.toole@bucknell.edu

Educational Bridge Building 201: Service Learning and Interdisciplinary Initiatives

T. Michael Toole, Dept. of Civil and Environmental Engineering, Bucknell University

Four principles from bridge design and construction can be applied to increase the depth of student learning and better integrate engineering and liberal arts perspectives. The four principles are:

1. Design a high bridge (set high expectations within a course)
2. Make students part of the construction crew (require students to start the learning process before they step into the classroom and create an active classroom)
3. Use composite materials (bring in perspectives and tools from other disciplines)
4. Connect important places (solve real world problems)

Successful service learning projects within and outside of the U.S. and a rigorous summer interdisciplinary program called the Institute for Leadership in Technology and Management will be used to illustrate the application of these principles.

Part IV: Presentations

The pdf files of the slides used in these Presentations are available in the electronic version of these Proceedings, and at the Symposium web site: www.union.edu/integration

Exploring the Legacy of a Liberal-Professional Vision of Engineering Education

Atsushi Akera, Associate Professor, Director, First Year Studies Program, Rensselaer Polytechnic Institute

Our dreams of integrating liberal and engineering education are not exactly new, but are firmly grounded in a long history reaching back to the origins of the modern engineering profession. From the Society for the Promotion of Engineering Education's (now ASEE) 1918 Mann Report, to the latest studies by the National Academy of Engineering, finding a way to elevate engineering through the proper integration of humanistic studies has remained an important focal point of engineering education reform initiatives. Beginning with a brief survey of the most substantial national efforts during the first half of the 20th century, this talk will focus on specific efforts undertaken by MIT, the Carnegie Institute of Technology (now CMU), and the Case Institute of Technology (now Case Western Reserve) to broaden engineering education. Among the specific topics addressed by this talk will be the unique professional configuration of engineering; efforts to present the integration of liberal and professional content as a superior and more egalitarian model of professional education preferable to those of law and medicine; the tension between a classically liberal versus instrumental view of the humanities; the struggle to resolve the paradox of a 'technological university'; and the impact of postwar engineering science ideologies. The particular circumstances—most notably the forces of economic globalization—that fuel the renewed interest in integrating liberal and professional content today are different from those that operated in the past. Nevertheless, by focusing on the experience of different private institutions, I hope to provide historical insights that will be beneficial to those assembled for this third Union College symposium on Engineering and Liberal Education.

The Power & the Glory: Making effective use of academic apostasy in pursuit of a truly student-centered curriculum

Alypios Chatziioanou, Director, Liberal Arts and Engineering Studies, Dept. of Civil and Environmental Engineering, College of Engineering; and David Gillette, Director, Liberal Arts and Engineering Studies, Dept. of English, College of Liberal Arts, California Polytechnic State University

Providing students with choice in shaping their academic life is a noble, oft-promoted goal, but giving true choice and freedom to students who have been systematically trained by restriction and academic confinement often creates confusion and sometimes results in academic paralysis. Universities enjoy discussing their commitment to student-centered learning, but disciplines that are defined and divided by dogmatic claims of legitimacy results in rigid curriculums resistant to change. Control over academic definition often directly equates to power and control over the faculty and resources that give life and meaning to that discipline. Tradition-bound disciplinary dogma is therefore intimately connected to the allocation and use of time, money, space and promotion.

Interdisciplinary, student-based learning often questions the dictates of academic dogma and therefore also comes in conflict with the control of departmental resources. Until the dogma defining academic disciplines is divided from resource control, interdisciplinary work will never gain the academic and institutional acceptance it needs to survive, and academics who labor between disciplinary walls will always be cast out and labeled as apostates.

Our paper examines how small, insurgent interdisciplinary programs can make use of the apostasy of discarding established academic dogma in the quest toward creating meaningful, progressive curriculums. We provide a number of recommendations about how careful advising and mentoring—with a full appreciation for the resistive power and perceived glory of academic division—can help students succeed when control over their educations is placed in their hands, possibly for the very first time in their academic lives.

Engineering Integrated Education: Oh The Places We Can Go!

T. Michael Toole, Dept. of Civil and Environmental Engineering, Bucknell University

The design process taught in an introduction to engineering class is applied to solve the problem that Colleges of Engineering and Arts and Sciences are not effectively integrated. For example, EBI and other data indicate that engineering students are not effectively integrating the perspectives from their required humanities and social sciences courses into their engineering designs. Four solutions are proposed:

1. A general engineering degree
2. Participation in the NAE Grand Challenges program
3. Requiring all students to take an integrated perspectives course, perhaps during a summer
4. Service learning projects

Successful interdisciplinary summer courses and domestic and international service learning projects will be used to illustrate the last two proposed solutions.

Building Bridges to Engineering

Robbie Berg and Theodore Ducas, Dept. of Physics; and Franklyn Turbak, Dept. of Computer Science, Wellesley College; Gill Pratt and Brian Storey, Franklin W. Olin College of Engineering

The National Academy of Engineering has identified a list of "Grand Challenges" that includes problems like providing access to clean water, making solar energy economical, preventing nuclear terror, and restoring and improving urban infrastructure. Such problems are not simply technical, but also involve social, political, economic, and aesthetic dimensions. How can we transform our educational system to better prepare our students to tackle such interdisciplinary challenges?

An important step is to build more bridges between engineering and the liberal arts. Engineering students clearly need to learn about human factors in addition to acquiring technical skills. And all liberally educated students should have some exposure to engineering so that (1) they can have a deeper understanding of proposed solutions to the key problems facing our planet and (2) some will be inspired to follow an educational path that will allow them to contribute to solving these problems. Students equipped with the breadth of a liberal arts education in combination with a strong technical background will be well positioned to make the socially effective technological advances represented by the Grand Challenges.

At Wellesley College, a liberal arts college without an engineering program, we have been exploring ways to introduce students to engineering. One of our goals is to present the "big ideas" of engineering to students majoring in disciplines across the curriculum. Another goal is to awaken the "inner engineer" in some of our students. Wellesley has cross registration arrangements with two nearby engineering institutions (Olin College and MIT) and engineering graduate programs are often willing to consider students who have majored in the sciences and have at least some engineering background. We wanted to create entry points for our students to be able to follow these paths.

In this presentation, we will describe our experiences since 1996 with two introductory courses that serve as bridges to engineering: Robotic Design Studio, a LEGO robotics course culminating in an exhibition that is more inclusive and provides more room for artistic expression than contest-centered formats; and Introduction to Engineering, a course co-developed with Olin College that introduces students to the design and implementation of mechanical systems, feedback and control, modeling, and simulation

Engineering Ethics and the Evolutionary Principles of the Universe

George Catalano, Professor of Bioengineering, SUNY Binghamton

The eco-theologian Thomas Berry and physicist Brian Swimme writing in *The Universe Story* (1994) offered the following three fundamental principles which govern evolution in the Universe: differentiation, subjectivity and communion. The principle of differentiation can be seen in the vast array of celestial bodies from galaxies to stars to planets to moons to comets to the dozens of elements that make up the periodic table, and the proliferation of species in bacterial, fungal, plant and animal world. Subjectivity refers to the latent possibilities that exist within each life form. Communion describes the highly interconnected web of life that characterizes our planet's ecosystems. The present work seeks to develop an engineering ethic that is consistent with these principles. An argument is offered that an engineering decision which diminishes the diversity of life on our planet, one that ignores the interests, hopes and fears of each living being or damages the fabric of the connectedness that exists is judged to be unethical. In contrast, a decision that promotes diversity, recognizes life's potentialities and respects the interconnectedness of life is judged to be ethical. An engineering ethic is offered which is consistent with these three fundamental principles. The new ethic is then applied to various cases of importance in modern engineering including issues of peace and security, development, and health of the environment.

Introducing the 'Missing Basics': Redefining the concepts of rigor and basics in engineering education

Russell Korte, Assistant Professor, College of Education, iFoundry Fellow, College of Engineering; David E. Goldberg, Professor of Entrepreneurial Engineering and co-Director of iFoundry, University of Illinois at Urbana-Champaign; and Mark Somerville, Franklin W. Olin College of Engineering

Goal: The goals of this interactive presentation are to critique the concepts of rigor and basics in engineering education. We introduce a broader view of engineering education by expanding beyond the narrow constraints of math and science. The "missing basics" support an emerging vision of engineering that encourages a wider view of the profession, along with an enhanced social role.

Content: Since the 1950s the basic skills taught in engineering education have focused almost exclusively on math and science. A key notion is that facility in science and math comprise the basis of engineering expertise (Note that we do not discount the importance of these skills; we propose that there are other important skills that are missing in engineering education). This presentation will facilitate audience discussion of the notion of the basics of engineering education as a conceptual issue regarding what is believed to constitute a rigorous education. Based on nearly 20 years of experience with students in a senior design course, we propose a set of "missing basics" derived from observations of what students cannot do when analyzing and resolving "real world" engineering problems. The missing basics fall outside the traditional concept of a rigorous engineering education and thus, educators face conceptual and philosophical obstacles trying to integrate them in engineering curricula. By examining and redefining the concepts of rigor and basics we attempt to help reduce the obstacles to effecting curricula change.

Part V: Alumni/ae Panel

Ilona Johnson, Smith '06

Senior Energy Engineer, EMO Energy Solutions

Ilona Johnson is a Senior Energy Engineer with EMO Energy Solutions, where her work focuses on helping organizations cost-effectively reduce resource consumption, greenhouse gas emissions, and waste. As a 2006 graduate from Smith College's Picker Engineering Program, she regularly draws from her interdisciplinary education to solve multi-faceted energy and environmental problems. To date, she has participated in energy audits that identified total savings opportunities of around 49 million kWh and 2 million therms, enabling greenhouse gas savings equivalent to removing 8,000 passenger cars from the road. Prior to joining EMO, Ms. Johnson provided support for the Department of Energy Office of Energy Efficiency and Renewable Energy (EERE) where her work included industrial technology assessments, energy policy analysis, and R&D portfolio support across multiple disciplines.

Peggy Miller, Union '74

Of Counsel at Roberts Ritholz Levy Sanders Chidekel & Fields LLP

Peggy A. Miller is an attorney and business advisor with more than 30 years of experience in interactive services and technology law, including advising, negotiating and drafting materials related to: new product development; interactive communications; online marketing, sales, advertising and sweepstakes; Internet web sites, Intranets, portals and social networking sites; software development and licensing arrangements, including open source software issues, hosting services and escrow agreements, joint-venture agreements, asset acquisitions and sales, master technology consulting agreements; domestic and international outsourcing agreements, including agreements for foreign outsourced credit card and data processing activities, and for modification, use and ownership of third party software for in-house data processing; domain name purchase and sale; international business arrangements; due diligence for M&A and securitization transactions regarding IT and Internet assets and license agreements; compliance with COPPA, DMCA and other laws regarding collection, hosting and electronic transmission of financial and other personal data (including insurance data) and user content, and with laws and regulations regarding security and privacy for Web sites and portals (including collection and use of social security numbers).

Ms. Miller is currently Of Counsel at Roberts Ritholz Levy Sanders Chidekel & Fields LLP, a small NYC firm with expertise in the entertainment, media, fashion and technology industries. Ms. Miller was Of Counsel at Dewey & LeBoeuf (and predecessor firms) from 1995 through 1Q2009, and was at Prodigy Services Company from 1985-1995 in various senior positions including Executive Director and Group Counsel, New Business Ventures, Associate General Counsel and Director of Commercial Operations.

David Robertson, Dartmouth '84, Thayer '85

VP of Analog Technology, Analog Devices, Inc.

David Robertson is Vice President of Analog Technology at Analog Devices, Inc., the world leader in data conversion and signal conditioning technology. In this position, Dave works across all organizational teams to coordinate and leverage ADI's considerable technical expertise to best serve customers. He joined ADI in 1985 and has worked on high-speed converter product design in a variety of process technologies, including complementary bipolar, BiCMOS, and submicron CMOS. Previously, as product line director for the High-Speed Signal Processing business unit, he directed both core converter development and the mixed-signal product strategy focusing on broadband communications applications. He has served on the Technical Program Committee for the ISSCC (International Solid States Circuits Conference) since 1999 and has served as chair of the Analog/Data Converter subcommittee from 2003 through 2009. Dave is an active member of ISTAC (Information Systems Technical Advisory Committee), a joint committee of industry and government members working to advise on technology export controls. Dave has authored numerous technical papers and award-winning presentations for venues such as the ISSCC and the VLSI Symposium. He was awarded 16 patents on converters and mixed-signal circuits. Dave received the Bachelor of Arts degree with a dual major in economics and engineering sciences, and the Bachelor of Engineering degree, both from Dartmouth

Part VI: Getting to Best Practices

1. Getting to Best Practices: Integration in Courses

Courses designed to specifically integrate the liberal arts and engineering/ technology for students of all disciplines. Discussion will address the following issues among others: learning activities for a mixed audience, team teaching, dealing with institutional challenges, what makes a good course.

Moderator: Mike Hagerman, Union
Issue Framers

- Polly Piergiovanni – Lafayette
- Linda Head – Rowan

Participants:

Alypios Chatziioanu, Cal Poly
Ted Ducas, Wellesley
Ashraf Ghaly, Union
Steve Hart, U.S. Military Academy
John Krupczak, Hope
Dan Miller, Colorado School of Mines
Jenn Stroud Rossmann, Lafayette
Hank Yochum, Sweet Briar

Learning activities for a mixed audience
We identified the following types of activities:

1. debate/class discussion
2. oral presentations
3. writing assignments
4. studio labs
5. final projects
6. art shows
7. community project showcase

We identified the following **best practices:**

1. Use studio format for lecture/labs
2. Get your hands dirty and go out on a limb and challenge yourself and the students
3. Incorporate active learning activities that are connected to course learning objectives
4. Create interdisciplinary student groups with a common objective
5. Encourage activities that showcase and value distinct views of each discipline and that require teamwork between disciplines to achieve objective

Team teaching
We identified the following key issues:

1. Multiple models work
2. Need to avoid relying too heavily on one instructor's knowledge and expertise

We identified the following **best practices:**

1. Teachers and students need to be passionate about central themes of study
2. Connectedness of ideas should be valued and encouraged through learning activities that focus on cross disciplinary interfaces with clearly defined objectives

Dealing with institutional challenges
We identified the following key issues:

1. Navigating the curricular process and getting approval
2. Lecture/lab coordination
3. Finding and securing the right space for activities
4. Faculty loading
5. Balancing program and department needs
6. Aligning goals of interdisciplinary program with goals of departments
7. Sustaining the course and teaching collaborations

We identified the following **best practices:**

1. Reward faculty for their efforts
2. Provide course release from departmental courses
3. Make new hires at interdisciplinary level
4. Go after external and internal funding
5. Use positive public relations to fuel curricular change
6. Link activities to departmental and college/university missions

What makes a good course?

We identified the following key issues:

1. Course must meet a need
2. Use models and real numbers
3. Make ethical questions central to themes
4. Engage students in details of perspectives from multiple disciplines

We identified the following **best practices:**

1. Makes sure instructors are passionate, invested and compatible
2. Use student directed learning
3. Model respect in dialogue and actions that communicate both sides
4. Use case studies that are relevant to current events
5. Make it sustainable through establishing permanent faculty loading within existing departmental structures and money for course activities/labs

2. Getting to Best Practices: Integration in extra/co-curricular activities

Ongoing activities outside of the classroom that involve majors from different disciplines working on technological challenges. Discussion will address the following issues among others: attracting multiple majors, dealing with institutional challenges, attracting funding, measuring student benefits.

Moderator: Joshua Smith, Lafayette
Issue Framers

- Ari Epstein – MIT
- Chun Wai Liew – Lafayette

Participants:

David Gillette, Cal Poly San Luis Obispo
Adrienne Klein, CUNY
Philip Maese, Rowan University
Cherrice Traver, Union College

Issues Discussed/Raised

- Examples of Extra/co-curricular activities on our campuses: Engineers Without Borders, art projects, Poly House Project
- Facilitating projects that are of durations not consistent with academic terms
- Rewards for students and faculty (credit, intrinsic, etc.)
- Empowerment of students

Best Practices

- Extra-curricular activities should give students an opportunity to do what they are inspired and passionate to do
- Despite the intrinsic reward of extra-curricular activities, there should be public recognition of their work and success.
- Students and faculty move on, so there should be a process of transitioning authority to new generations of people involved. There should also be archival documentation of project work.
- There is a value to music, art, and service. Students have a passion for it, but need venues in which is it expectable to explore this. Since extra-curricular activities have no grades associated, students are freer to fail.

Discussion (roughly transcribed)

Epstein: Extra-curricular activities are things that students are or should be inspired to do, since they are on top of everything else they do. The MIT Idea Prize, students compete in an expo for foundation funding to implement their ideas.

Liew: Recognition is a big carrot for students. They enjoy the public presentation of their work to their friends.

Epstein: Students like seeing that their work mattered.

Gillette: The Poly House Project at Cal Poly San Luis Obispo (http://polyhouse.wordpress.com) is a project in which students undertake extensive renovations of a local community member's house [think of a cross between Extreme Makeover: Home Edition and Habitat for Humanity]. Some students earn course credit but many do not. They all see the huge impact on the family because of their renovations.

Liew: The students see that they can achieve something. They are not being told by faculty or others what they cannot do.

Gillette: Students become empowered through this experience because they see what they can accomplish. They take this empowerment and then succeed in their courses.

Smith: How is fundraising accomplished for this project?

Gillette: Fundraising occurs through a course. Both the faculty and students get credit for the course.

Smith: Not all extra-curricular activities work well with the structure of an academic term. Engineers Without Borders works on multi-year projects, and students participate for many years.

Epstein: There needs to be a transition of knowledge and authority from students to students.

Gillette: There needs to be a process by which knowledge is passed from group to group, such as creating archival documentation. If students have their own project notebooks, these need to be transcribed for archives. Technical writing classes may be used for this purpose. But this requires relationships between faculty members to facilitate.

Gillette: Cal Poly Lands Project. Hiking and mapping local wooded area.

Epstein: Audio recordings can be done using iPhones, and those recordings could be transcribed at a later date.

Maese: Students can be rather shy. There is an emotional value to art, music, service that may help them overcome their shyness.

Liew: Students have passion. For my art projects, they want to exhibit their work and receive recognition.

Epstein: Students need to see their passion as acceptable. Extra-curricular activities can facilitate this because there are no grades.

Liew: The extra-curricular activities need to provide an environment (opportunity, funding, etc.) where it is safe to experiment and possibly fail.

Gillette: I advocate the opposite. Students at Cal Poly do projects that help them determine their career path. Find external mentors to help them with this. They make presentations, which helps them with their presentation skills.

Epstein: Creation of a safe space for students to be open, where failure is okay.

Epstein: Alumni may be excited to mentor students.

Epstein: Extra-curricular activities serve the other part of a person.

3. Getting to Best Practices: Faculty integration

Faculty from the liberal arts and engineering collaborating on various initiatives such as research, service, curricular, etc. Discussion will address the following issues among others: finding a collaborator, including this as part of the faculty reward system, dealing with institutional challenges, measuring the benefits to faculty.

Moderator: Andrew Guswa – Smith
Issue Framers

- Andy Smith – Lafayette
- Ann Anderson – Union

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Discussion:

There are four broad areas in which faculty integration can occur: (1) teaching, (2) research (in each case, these can be integrative teams, or individual polymaths working taking multiple disciplinary perspectives), (3) interdisciplinary or joint hiring, and (4) finding less formal institutional ways to bring faculty together to spark conversation.

Drew started out by reviewing some of the conclusions reached at the discussion session last year (2009) that dealt with similar topics. While recognizing that we cannot rely solely on tenured faculty, and need to involve junior faculty, last year the discussion started by skipping past the hiring, tenure and promotion issue, and assumed faculty were tenured.

There were four ways by which existing (tenured) faculty could be supported in their ID efforts:

1. A clear articulation by administrative leadership that interdisciplinary activity is valuable.
2. Financial support, even if in token amounts, to indicate that the institution places value on making contributions to interdisciplinary projects/programs.
3. Time support, where possible (loading hours or release).
4. Articulating models of success; providing case examples of successful ID faculty.

One good way to bring about change is through “immigration.” Cultural change happens by bringing in people with new attitudes and values. This leads to the challenging issues surrounding interdisciplinary hiring, promotion and tenure, and led to the following suggestions/observations:

- Form cohorts. New junior faculty are not already wedded to a particular success trajectory and if they embark on the journey together, they are more inclined to collaborate. This may or may not be practical for smaller schools who generally bring in one person at a time.

- Institutional support is necessary, but not sufficient. Now, scholarship is generally judged by disciplinary field, not by the contribution to the institution. Need to persuade colleagues to respect people with a different mission; perhaps there should be more focus on the *impact* of publications, not a strict count. Rick Miller noted that his most often cited publications are not the deepest disciplinary works, but rather the most interdisciplinary works.

- Faculty working in interdisciplinary areas need to receive clear statements of institutional expectations. This can be done through memoranda of understanding for joint and interdisciplinary hires and careful medium- to long-range planning for both faculty members and programs.

- There should be the opportunity for formal and informal mentoring of faculty in non-traditional positions, in order to assure good pre-tenure faculty development.

Best Practices:

The discussion next turned to models of how to bring people together.

- It does not necessarily work to pull all like-minded people together and sequester them away from their traditional home. This removes their desire to integrate from the rest of their department, and may make the original departments even more rigid.

- A better model is to pull like-minded people together under an integrative umbrella, but not sever their ties to their department of origin. iFoundry at UIUC, the School of Information Science at Michigan, and the School of Arts, Media and Engineering Arizona State University were cited as good examples

- Less formal methods of integration include team teaching, sharing cross-disciplinary modules, "massively" interdisciplinary courses which engage faculty from many different areas for short times, paired courses which meet together occasionally for joint lectures, labs, or other projects

- Another way to bring people together is to create an exciting challenge or problem that induces faculty to spend time together, like the Lafayette "Corn on the Quad" project, the Union College time capsule or trolley tracking projects, or the Rollins College faculty tours that Lewis Duncan described last year.

- We noted that "success breeds success," so to get more faculty to practice disciplinary integration we need to generate some visible success stories.

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Council for Environmental Deans and Directors, policy paper on ID hiring: http://www.ncseonline.org/CEDD/cms.cfm?id=2042

School of Arts, Media + Engineering at Arizona State University http://ame.asu.edu/

iFoundry at UIUC http://ifoundry.illinois.edu/

U. Michigan School of Information: http://www.si.umich.edu/about-SI/mission.htm

Evergreen State College's program pages: http://www.evergreen.edu/about/programpages.htm

Union trolley page: http://trolley.union.edu/
Union time capsule page (on Facebook): http://www.facebook.com/#!/group.php?gid=175345595851&ref=ts

4. Getting to Best Practices: B.A. Engineering (Type) Programs

Various colleges/universities have interdisciplinary undergraduate degrees designed to integrate the liberal arts and engineering. Discussion will address implementation issues versus ongoing issues for those involved or contemplating such programs.

Moderator: Eric Hansen, Dartmouth
Issue Framers

- Borjana Mikic – Smith
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Discussion:

The session began with brief descriptions of three engineering B.A. programs, at Smith, Lafayette, and Dartmouth, and continued with discussion.

At Smith and Lafayette, the B.A. is an alternative track to the accredited B.S. program. At Dartmouth, the B.A. is prerequisite to the accredited B.E., which requires up to an additional year of study. The B.A. programs require all or nearly all the same prerequisite math and science courses as their institution's B.S. or B.E. programs. The fundamental engineering science and design courses are a subset of those taken by B.S. or B.E. students.

The Lafayette program in Engineering Studies achieves a deliberate integration of engineering and liberal arts via a three course core in engineering and public policy, engineering economics and management, and engineering and society. Smith expects each student in the Engineering Arts major to have six courses in a focus area outside of engineering and to prepare a written statement explaining how these courses integrate with her engineering studies.

The discussion brought out several common features, issues, and best practices.

1. It is important that faculty, admissions, and career services be clear about the mission of the B.A. program. It was emphasized that the B.A. is not meant to be a bailout path for students unable to "handle" an accredited program. Rather, by design it provides a different balance of engineering and liberal arts to prepare students for other careers. While engineering B.A. graduates may work in technical organizations in non-design areas like sales and marketing, they also bring a higher level of technical knowledge to non-engineering professions such as law, medicine, government and policy, and education.

2. It is also important that administration understand the unique mission of the B.A. program so that sufficient resources are provided. Even if there are no special courses for B.A. students, they are enrolled in other engineering courses and still need faculty advising, particularly as they shape their courses of study to their particular interests.

3. B.A. programs have a different academic pace that while still demanding is more appealing to many students and often attracts "late bloomers" who don't initially think of studying engineering.

4. Finally, B.A. programs provide opportunities to leverage the resources of other academic departments. For example, Dartmouth allows students to construct modified majors—engineering and economics, engineering and studio art, engineering and public policy, as well as engineering and other sciences.

Part VII: Appendix

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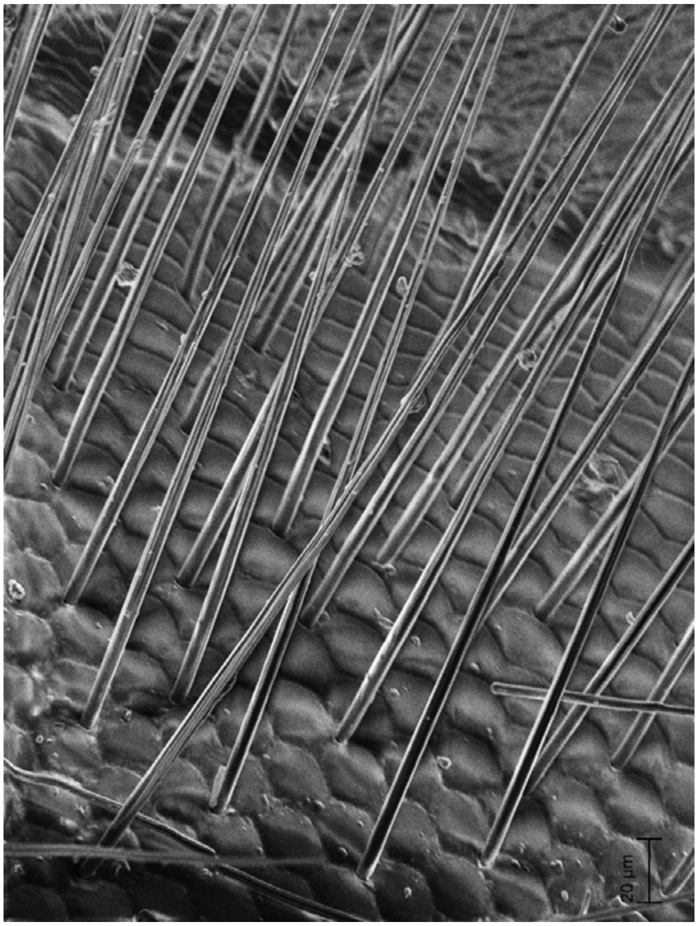
Back Cover: SEM Visualization

Working with the SEM has presented me with a new horizon in my exploration of the visual world as a fine art and documentary photographer. I have always considered the camera and photography as tools for creating bridges of understanding between the viewer and the visual realities of our world. Photography can stir our curiosity by presenting us with new ways of seeing the familiar as well as familiar ways of encountering the unknown.

As a documentary photography who for years photographed throughout the Himalayas I was fascinated by how the SEM allows us to see the real world in ways that go beyond our regular visual encounter with our environment. The SEM technology lets us view the sample specimen from above as if doing aerial reconnaissance and then drop down onto the surface of the sample with an intimacy of exploring an unknown intriguing landscape on foot.

For a number of sessions at the SEM I have explored one honey bee. Through the visualizing technology of the SEM the honey bee has become an entire world of exploration with landscapes that change from what appear to be fern or bamboo forests to thorn thickets of the bee's abdomen to broad expanses of spiked landscapes of the bee's wings. When I navigate the surfaces of the honey bee in search of compelling and beautiful visual compositions I cannot help but think of the photographic landscapes of Edward Weston, Ansel Adams and Paul Caponigro, the drawings of Albrecht Durer and Leonardo da Vinci, or the accomplished artful drawings by one of the very first microscopists Robert Hooke.

Kevin Bubriski
Adjunct Associate Professor of Photography Union College 2009-2010



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