Engineering Curricula: Understanding the Design Space and Exploiting the Opportunities: Summary of a Workshop

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Summary of a Workshop

Ryan C. Davison, Rapporteur

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This workshop summary has been reviewed in draft form by individuals chosen for their diverse perspectives and expertise, in accordance with procedures approved by the National Academy of Engineering (NAE). The purpose of this independent review is to provide candid and critical comments that will assist the author and the NAE in making the published report as sound as possible and to ensure that the workshop summary meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this workshop summary:

Eli Fromm, Drexel University
Hayden Griffin, Virginia Polytechnic Institute and State University
Lueny Morrell, Hewlett Packard Company
Stanley Napper, Louisiana Tech University

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the final draft of the report before its release. The review of this workshop summary was overseen by **Michael Corradini** of the University of Wisconsin. He was responsible for making sure that the independent examination of this workshop summary was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this workshop summary rests entirely with the author and the institution.

Contents

Summary

In April 2009, with support provided by the National Science Foundation, the National Academy of Engineering's Committee on Engineering Education hosted a one and one-half day workshop focused on exploring how engineering curricula could be enhanced to better prepare future engineers. The workshop included individuals from industry, university faculty and administrators, and representatives from government agencies and professional societies.

Topics addressed in the workshop included (a) the rationale for the scope and sequence of current engineering curricula, considering both the positive aspects as well as those aspects that have outlived their usefulness, (b) the potential to enhance engineering curricula through creative uses of instructional technologies, (c) the importance of inquiry-based activities as well as authentic learning experiences grounded in real world contexts, and (d) the opportunities provided by looking more deeply at what personal and professional outcomes result from studying engineering.

General themes that appeared to underlie the workshop attendees' discussions included desires to (a) restructure engineering curricula to focus on inductive teaching and learning, (b) apply integrated, just-in-time learning of relevant topics across STEM fields, and (c) make more extensive use and implementation of learning technologies.

During breakout discussions, many suggestions were offered for means by which to facilitate curricular innovation. These included (a) expanding faculty and administrator communication networks, (b) increasing faculty incentives, and (c) enhancing interactions among stakeholders of engineering education.

1

Introduction

MOTIVATION FOR THE WORKSHOP

Previous National Academies reports[1,2] have demonstrated that engineering research, innovation, and education are occurring in an increasingly globalized context. In order to meet the demands created by rapidly changing social and political realities, as well as new scientific and technological opportunities, it is crucial to continually advance how engineers are trained and educated. An imperative for our nation's prosperity is the preparation of future engineers who can thrive in highly dynamic environments, and to successfully train the engineers of tomorrow, greater attention must be paid to the content and delivery of engineering curricula.

PURPOSE AND CONDUCT OF THE WORKSHOP

In April 2006, The National Academy of Engineering (NAE) was asked by the National Science Foundation to organize a workshop to discuss, critique, and offer alternatives to existing models of engineering curricula. The NAE formed an engineering curricula workshop organizing committee, chaired by Eli Fromm, under the auspices of the Committee on Engineering Education. The committee held a workshop March 23-24, 2009, in Washington, DC, focused on enhancing engineering curricula and exploring how to better prepare future engineers. The workshop included individuals from industry, university faculty, administrators, and representatives from governmental agencies and professional societies, in order to explore comprehensive alternative curricular models capable of supporting student learning as envisioned by the ABET accreditation criteria[3] and the Engineer of 2020 reports.[4,5]

The agenda for the workshop is given in Appendix A. Workshop participants included members of the workshop organizing committee, and invited guests from industry, academia, and professional societies who were familiar with engineering curriculum design. See Appendix B for a list of participants. The workshop was not a consensus-building activity. This report is intended to summarize the main points made

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[1] The National Academies (2007), *Rising Above the Gathering Storm*, Washington, D.C.: The National Academies Press.
[2] NAE (2005), *Engineering Research and America's Future*, Washington, D.C.: The National Academies Press.
[3] ABET Engineering Accreditation Commission (2008), *Criteria for Accreditation of Engineering*, Baltimore, MD, ABET, Inc. http://www.abet.org/forms.shtml#For_Engineering_Programs_Only [Accessed April 9, 2009].
[4] NAE (2004), *The Engineer of 2020: Visions of Engineering in the New Century,* Washington, D.C.: The National Academies Press.
[5] NAE (2005), *Educating the Engineer of 2020: Adapting Engineering Education to the New Century,* Washington, D.C.: The National Academies Press.

and actions suggested from the workshop's "breakout sessions" and capture the related themes. It does not provide consensus findings or recommendations.

In planning the workshop, the committee sought to have the flow of the presentations and subsequent discussions advance the overall workshop aim of developing new curricular models. Keynote talks were identified with the aims of (a) explaining the reasons for the scope and sequence of current engineering curricula with emphasis on the positive aspects as well as those aspects which may have outlived their usefulness, (b) indicating the potential to enhance future engineering curricula through creative uses of instructional technologies, (c) emphasizing both the importance of inquiry-based activities as well as authentic learning experiences grounded in real-world contexts, and (d) highlighting the opportunities provided by looking more deeply at what personal and professional outcomes result from studying engineering.

In opening the workshop, Charles Vest, President of the NAE, summarized the relatively low representation of baccalaureate engineering degrees in the US compared with countries in Europe and Asia and noted that President Obama is calling for more young people to enter the engineering profession. He emphasized the importance of getting the word "engineer" used directly and distinctly as part of conversations about education and national industrial policy. He observed that making sure engineering schools provide students with stimulating and demanding environments is more important than specifying curricular details. He remarked that attempts to predict relevant curricular content in the past had proven unreliable and offered examples such as manufacturing (academic backwater in the 1980, but area of national crisis in 1990), and energy and power (academic backwater in 2000, but area of urgent national crisis in 2010). He suggested that university education should reflect the frontiers and synergies of fields of engineering. He then noted that the two major strands in engineering are the micro (i.e., nano-, bio-, info-) and the macro (energy, environment, health care, etc.); and that to effectively bridge these strands, engineers need to engage the expertise of natural and social scientists. However, successful bridging the strands will offer large societal payoffs in areas such as bio-based materials, personalized medicine, biofuels, synthetic biology, etc. He then summarized the NAE Grand Challenges for Engineering[6] and expressed his excitement at the strong resonance they have generated in the engineering community. He was particular enthusiastic about efforts to engage young faculty in an education-focused dialogue that would build a community of education innovators and aid in the propagation of innovations. He offered David Baker of the University of Washington an example of such a young innovator. Baker is an award winning Howard Hughes Medical Institute biochemist and adjunct professor of bioengineering doing leading edge work in protein folding. Baker and his co-workers, including students, developed the video game *Foldit*[7]. While users are engaged in the game, the computer is studying their pattern-recognition and puzzle-solving abilities to determine if there are there are human strategies that can be adapted to computer algorithms for folding proteins. The result could be faster understanding of protein structures and insight into how proteins might be targeted with drugs to treat diseases such as AIDS, cancer, and Alzheimer's.

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[6] See http://www.engineeringchallenges.org.
[7] See http://fold.it/portal/info/science [Accessed May 6, 2009].

In his opening remarks, Eli Fromm, the organizing committee chair, outlined the tasks before the attendees as being to explore the efficacy of commonly used curricular structures and curricular content as well as alternatives. The aim was to see if new curricular models might better draw upon theories of teaching and learning in order to deepen student learning of fundamental engineering concepts taught in core engineering courses. In addition to greater depth of learning of engineering fundamentals, Fromm posed a desire to have engineering students better demonstrate such professional skills as teaming, communication, and business acumen. He also challenged those present to think about how engineering curricula could better engage students who did not intend to become practicing engineers, but would nonetheless benefit from the skills and disciplined mode of thinking taught to engineers.

Four keynote addresses set the key themes to be considered by the workshop attendees: The origins of current engineering curricula, a future vision for engineering curricula, engaging students through grand challenges, and using the liberal arts model for engineering education.

Joseph Bordogna of the University of Pennsylvania offered a historical retrospective on the development of engineering as a field from ancient times to the present and on the development of US engineering education programs from the first program at the US military academy at West Point. He summarized the processes that lead to the emergence of new engineering disciplines and the consequent effect on the organization of academic departments. He also summarized the societal, economic, and political influences on academic engineering. Throughout his remarks, he weaved continual reinforcement of a message that engineers must be synthesizers who should pay little heed to boundaries, but must focus intently on serving societal needs.

Woodie Flowers of the Massachusetts Institute of Technology challenged attendees to take on the NAE Grand Challenge to “Advance Personalized Learning” by focusing faculty for the true challenges of education (e.g., learning to think using calculus, learning to communicate, learning to design, and understanding systems) and using computerized media for routine tasks better characterized as training (e.g., learning calculus, learning spelling, and grammar, learning computer-aided-design packages, and learning parts of systems). Drawing upon data from an MIT undergraduate’s thesis, he showed that although past MIT baccalaureate recipients believed they received a superlative technical education, they also believed there to be insufficient attention to professional skills (e.g., teamwork, communications skills, independent thinking, business skills, and societal context). Flowers then suggested a much greater emphasis on (a) learning by doing so as to promote understanding specific phenomena before understanding their generalized abstractions, and (b) learning as a collaborative discovery experience among students and between students and faculty mentors. He posited that technology had reached the stage where a “new media” model should be actively pursued. He explained the model as one in which entertainment-quality web-based modules are used for teaching. The web modules use cinema-quality animation, voice and video clips, captions, and text, all combined as appropriate in accurate, well organized, pedagogically solid productions. Achieving such technologies requires an adequate investment, but such investments are both possible and can generate adequate returns to make them worthwhile. He contrasted the relatively small number of authors and static content of the traditional textbook, with the very large number of contributors and engaging content of a commercial film or video game. He concluded by offering the film short on "The Inner Life of the Cell"[8] as an example of the type of complex information that could be clearly and effectively presented via the "new media" model.

Geoffrey Orsak, dean of engineering at Southern Methodist University, reflected on a "listening tour" he undertook upon assuming his position. A key theme he heard in many conversations with many different types of stakeholders was a desire to have engineering graduates who could meet societal needs (e.g., build an off-road wheelchair, design a glucose meter that does not use a needle, or design a highly efficient but low cost cooking pot for use in emerging economies). He urged a return to the heroic role of engineers that existed during the race to the moon in the 1960's. He believes that accomplishing this requires placing greater emphasis on educating future engineers by having them work on real problems that matter to real customers. He cautioned that doing this effectively may require operating outside of traditional curricular structures.

James Duderstadt, president emeritus of the University of Michigan, synthesized a wide array of nationally significant reports on engineering research, practice, and education in order to (a) identify current challenges to the further progress and development of engineering research, practice, and education in the US, (b) suggest goals for needed progress in engineering research, practice, and education, (c) look at the gap between where we are and where we need to be, and (d) offer a path forward to 21st century engineering. He summarized past reports as indicating (1) US technological preeminence requires its leadership in engineering research, practice, and education, (2) in order for US engineers to compete in a global economy, they must offer higher value than their international counterparts, (3) in order for US engineers to have needed influence in political and business domains, the profession must be elevated in prestige and influence, (4) to achieve the goals in items 1 through 3, preparation for professional research and practice in engineering should occur at the graduate level (as is the case with medicine and law) while the undergraduate study of engineering would become a liberal arts subject of study (as is the case with humanities and science courses). Duderstadt then offered specific recommendations in the areas of research, practice, and education for re-positioning engineering for the 21st century. He suggested that engineers should identify more with their profession than with their employers and that engineering research would benefit from a new model linking universities, industry, and government in collaborative research. Duderstadt then expanded upon his recommendations by urging more structured approaches to the lifelong learning of engineers, and urging all stakeholders to commit to greater racial, ethnic, and gender diversity among future engineers.

A panel of speakers opened a general discussion of curricular implications of emerging trends in engineering: engineering at the interfaces with other disciplines, the engineer's role in a global economy, the engineer's role in developing countries, and teaching leadership within engineering.

- David Goldberg of the University of Illinois spoke about evident opportunities in interdisciplinary collaboration, the conceptual barriers that impede interdisciplinary collaboration, strategies to mitigate the barriers and facilitate

[8] BioVisions at Harvard University, The Presidents and Fellows of Harvard College, 2007. http://multimedia.mcb.harvard.edu/anim_innerlife_hi.html [Accessed May 6, 2009].

collaboration, and examples of new interdisciplinary initiatives linking engineering and other fields.
- Norman Fortenberry of NAE highlighted the breadth of activities that are encompassed in the term "engineering," the national and societal contexts of engineering around the globe, country-specific and common themes in reports examining engineering education, and the desirability of moving toward "continuous improvement" in engineering education through pursuit of research on the process of engineering education both by engineering faculty and in collaboration with those in the learning sciences and other professions.
- Benjamin Linder of Olin College recounted the excitement and high engagement of his students when offered the opportunity to apply their engineering knowledge to the challenges facing real people in developing countries. The real-world exposure to socially relevant engineering problems reinforced their interest in engineering coursework.
- Lesia Crumpton-Young of the University of Central Florida (UCF), described the motivations for and content of engineering leadership programs. She reported on survey results showing the high value UCF students attach to their engineering leadership program in terms of advancing their social, communication, and business skills as well as greater confidence in the use of their technical skills.

Following the keynote and panel presentations, the workshop organizing committee believed it would be useful to engage attendees directly in group discussion of emerging roles served by engineers that should inform the design of future curricula. These include the engineer's role as a connector across disciplines, the engineer's role in community-based and socially-relevant projects, and the engineer's role as a leader. Appropriate "breakout sessions" were organized and attendees were divided into groups based upon their interest and expertise in the following subjects:

- Engineering education research findings that inform curricular innovation
- Models of enacted curricular innovation efforts and lessons learned
- Working with non-engineering faculty to achieve breadth and depth in engineering education innovation

The breakout group on curricular influences of engineering education research was led by Barbara Olds of the Colorado School of Mines and included Susan Ambrose of Carnegie Mellon University, Kurt Becker of Utah State University, Eliot Douglas of the University of Florida, PK Imbrie of Purdue University, Teri Reed-Rhoads of Purdue University, James O'Brien of the American Society of Civil Engineers, Tom Perry of the American Society of Mechanical Engineers, and Gloria Rogers of ABET, Inc. Group members were asked to respond to such questions as the following:

- What engineering education research trends are emerging and what are their implications for engineering curricula?
- What gaps exist between current engineering educational research and ideal research; what changes should be made?

- How can research findings become a part of sustainable innovation and change within engineering curricula?

There was limited discussion of the first question with reference made to findings emerging both individual researchers as well as national centers such as the Center for the Advancement of Engineering Education[9]. However, multiple suggestions were made by individual group members in response to the last two questions. These suggestions included: (a) looking at the nature of curricular innovation, (b) conducting research on those factors which promote the diffusion of curricular innovation, (c) developing tools and workshops to facilitate faculty sharing of research findings and the translation of research findings into innovative modifications of instructional practice, (d) building professional incentives and rewards for continual faculty attention to educational research as well as curricular and instructional innovation, and (e) assessing the professional performance and career paths of students under various curricular models so as to inform faculty, students, and employers about the value of innovative instructional and curricular methods.

The breakout group on enacted curricular innovations and lessons learned was led by Stan Napper of Louisiana Tech and included Joseph Bordogna of the University of Pennsylvania, Debbie Chachra of Olin College, Adam Fontecchio of Drexel University, Patricia Fox of Indiana University – Purdue University at Indianapolis and of the American Society for Engineering Education, David Goldberg of the University of Illinois, Robert Gufstafson of Ohio State University, Sherra Kerns of Olin College, Wendy Newstetter of Georgia Tech, Geoffrey Orsak of Southern Methodist University, Larry Shuman of the University of Pittsburgh, and Bob Warrington of Michigan Technological University. Group members were asked to respond to such questions as the following:

- What programs have significantly changed their engineering curricula?
- How are these programs succeeding and what lessons have been learned?
- How can these programs be improved and what sustainable new models need to emerge?

All members of this breakout group noted that each of their universities had changed its engineering curricula significantly within the past decade. Individual breakout group members identified engineering programs at other institutions that they considered to have experienced significant change over the same time period, specifically those at Carnegie-Mellon, Clemson, Penn State, Purdue, Rose-Hulman, Rowan, the University of Colorado at Boulder, and Worcester Polytechnic Institute.

Observations made by individual group members on lessons to be drawn from the examples offered included (a) individual champions are needed to initiate and sustain change, (b) support of key administrators such as deans is critical, (c) faculty and students

[9] See for example, Center for the Advancement of Engineering Education, "Findings from the Academic Pathways Study," released at Special Session 2530 at the 2009 Annual Conference of the American Society for Engineering Education held in Austin, TX, June 14-17, 2009. Available at http://www.lulu.com/content/paperback-book/caee-summary-findings-from-academic-pathways-study/7328287 [Accessed August 28, 2009].

must be engaged, (d) buy-in of faculty and students is facilitated by the provision of choice and flexibility, and (e) visible and prestigious support, such as that from National Science Foundation grants, can contribute to initiation, maintenance, and diffusion of program innovations.

Suggestions by individual group members for sustaining programs included (a) attracting and maintaining industrial interest and sponsorship, (b) use of student “user” fees, and (c) administrative and structure changes to institutionalize policies and procedures.

The breakout group on working with non-engineering faculty was led by Deb Hughes-Hallet, a mathematician at the University of Arizona and included Robert Beichner a physicist from North Carolina State University, Benjamin Linder of Olin, Donald McEachron of Drexel, Alan Tucker, a mathematician from Stony Brook University, and Linda Vanasupa of California Polytechnic State University at San Luis Obispo. Group members were asked to respond to such questions as the following:

- How can engineering faculty partner with math and science faculty to benefit engineering students?
- How can engineering faculty most effectively partner with social science, liberal arts, and business faculty in order to broaden the education of engineering students?
- How can engineering faculty most effectively partner with social science, liberal arts, and business faculty in order to enhance the technological awareness and understanding of non-engineering students?
- What model partnerships exist that provide lessons for answering the previous questions above?

Observations by individual members of this group included (a) interaction between engineering and non-engineering faculty was critical to achieving the curricular innovations needed to promote the broader education needed by engineering students, (b) a pre-requisite for addressing any of the questions posed was to better understand how to improve interactions, in general, between engineering and non-engineering faculty, (c) there is a perceived a lack of respect on the part of engineering faculty for the methods and theories underlying the scholarship and research conducted by their non-engineering peers, particularly those in the social sciences and humanities, and (d) a strong need exists to promote greater open mindedness among engineering faculty that would facilitate collaboration on creative and reflective pursuits. Several suggestions were made by individuals on how greater open mindedness might be promoted. These included (a) encouraging engineering faculty to make sure their students understand how messy and complex real-world problems are and, thereby, encourage their gaining an appreciation for the level of assumptions and approximations present in engineering work, (b) encouraging faculty understanding of their students perspectives by supporting engineering faculty to audit non-engineering courses and non-engineering faculty to audit engineering courses, and (c) promoting collaborative teaching by engineering and non-engineering faculty.

The global themes that emerged from the breakout sessions are summarized by topic area in Section 2. Specific observations from the breakout sessions are presented in Section 3.

2

General Themes

While a variety of curricular issues were identified during workshop discussions, three overlapping global themes clearly emerged. They included (a) the need to restructure engineering curricula to focus on inductive teaching and learning, (b) the importance of applying integrated, just-in-time learning of relevant topics across the STEM fields, and (c) the need to increase significantly the use and implementation of learning technologies. In the text below, each one of these global themes is examined and observations that flowed from the workshop are noted.

RESTRUCTURING ENGINEERING CURRICULA TO FOCUS ON INDUCTIVE TEACHING AND LEARNING

Techniques for teaching engineering and science are traditionally deductive. That is, they tend to introduce the general principles of a topic in a classroom lecture, develop mathematical models using those principles, demonstrate how these models may be applied, assign homework where these models must be applied, and finally, test the student's performance to do similar work on an exam.[10] Deductive instruction begins with the proposal of a concept, and the explanation of the concept follows, often in a rigid pattern of exposing students to a general rule, offering specific examples and requesting students practice.[11]

An instructor practicing inductive teaching methods would first illustrate to students why a certain academic principle is important, require some sort of practice, often real world, and *only then* propose the general rule or lesson.

Felder and Prince[12] note that

> Inductive teaching and learning is an umbrella term that encompasses a range of instructional methods, including inquiry learning, problem-based learning, project-based learning, case based teaching, discovery learning, and just-in-time teaching. These methods have many features in common, besides the fact that they all qualify as inductive. They are all *learner-centered* (also known as *student-centered*), meaning that they impose more responsibility on students for their own learning than the traditional lecture-based deductive approach. They are all supported by research findings that students learn by fitting new information into existing cognitive structures and are unlikely to learn

[10] Prince, Michael, and Richard Felder. "Inductive Teaching and Learning Methods: Definitions, Comparisons, and Research Bases." *Journal of Engineering Education*, vol. 95, no. 2, (2006): pages 123-38.
[11] Stern, Hans Heinrich. "Issues and Options in Language Teaching." Oxford University Press, 1992.
[12] Prince, Michael, and Richard Felder. "Inductive Teaching and Learning Methods: Definitions, Comparisons, and Research Bases." *Journal of Engineering Education*, vol. 95, no. 2, (2006): pages 123-38.

> if the information has few apparent connections to what they already know and believe. They can all be characterized as *constructivist* methods, building on the widely accepted principle that students construct their own versions of reality rather than simply absorbing versions presented by their teachers. The methods almost always involve students discussing questions and solving problems in class (*active learning*), with much of the work in and out of class being done by students working in groups (*collaborative* or *cooperative learning*).

A focus on the elements of inductive teaching provided a common thread within the keynote addresses by Bordogna, Flowers, Orsak, and Duderstadt. Many workshop attendees were supportive of Duderstadt's suggestion that a professional graduate degree in engineering provide the gateway to research and practice as an engineer. They saw Duderstadt's vision of undergraduate engineering coursework as a liberal arts subject as providing a means to address Fromm's opening challenge to engage non-engineering majors in the benefits of studying engineering.

Discussants in the breakout group focused on "existing curricular models and lessons learned" observed that some courses possessing significant innovations are predominately inductive in nature. These include (a) programs at the University of Pittsburgh, where students spend spring break engaged in a variety of cultural and technical activities in Asian countries, (b) a cognitive apprenticeship at the Georgia Institute of Technology, in which faculty facilitate first-year learning by working in problem-solving groups in classrooms with writable walls extending from the floor to ceiling in order to stimulate thinking in terms of diagramic representations, (c) a program at Olin College, in which engineering students start and run a business as a team, with all profits donated to charity, similar to a project immersion program at Southern Methodist University and an Enterprise Program at Michigan Tech, and (d) Living with the Lab, a project-centered interdisciplinary, integrated engineering/math/science curriculum for all first-year engineering majors at Louisiana Tech. One person noted that in 1996 the American Society of Mechanical Engineers (ASME)[13] started inductive curriculum reform to create an environment of active, discovery-based learning, in which multi-disciplinary "enterprise teams" advocated advancing engineering education. Another attendee noted that the calls by Duderstadt and Bordogna for integrating technical and educational research findings into classroom instruction provides further opportunities for inductive instruction.

APPLY INTEGRATED, JUST-IN-TIME LEARNING, OF RELEVANT TOPICS ACROSS STEM FIELDS

Several attendees observed that Flower's presentation suggested an opportunity to make greater use of just-in-time learning. Just-in-time learning offers learning opportunities that can be structured and delivered exactly when an individual needs them, and allows for the acquisition of knowledge or skills at a point in which a student is most

[13] ASME Curricular Innovation Awards http://www.asme.org/Governance/Honors/UnitAwards/Curriculum_Innovation_Awards.cfm [Accessed May 6, 2009].

receptive.[14] An illustration of just-in-time teaching would be an interaction between online study assignments and an active learner classroom. For example, students could respond electronically to web-based coursework due shortly before class, allowing the instructor to consider student performance "just-in-time," and adjust the classroom lesson to suit the students' needs.[15]

Some workshop participants expressed the hope that implementing just-in-time learning and teaching could strengthen efforts to address better the informational needs of students with varying skill sets. An example was offered from Olin College where students have the option to create their own engineering program, allowing undergraduates to pursue individual interests using differing timetables. This program is referred to as the E:Self, and its flexibility allows for the interdisciplinary integration of other curricula into traditional engineering paradigms. Self-directed learning, both in terms of time course and curriculum, is a large component of programs such as E:Self that are designed with the aim of fostering a student's sense of engagement and control.

INCREASE THE USE AND IMPLEMENTATION OF MODERN LEARNING TECHNOLOGIES

A concern echoed by many of the workshop participants was that the current classroom paradigm, in which nearly all teaching efforts consist of the instructor explaining information from a textbook, is archaic and must be changed. It was noted that the modern textbook has evolved very little from its origins in 1871 when Christopher Columbus Langdell, a law professor at Harvard, decided that compiling thick, imposing casebooks, with hundreds of appeals court rulings, should be the foundation of legal teaching.[16] Flowers made a similar point in his keynote address.

Many workshop attendees commented that the keynote and panel speakers had proposed a variety of innovative examples of the use of modern learning technologies including Vest's citation of the David Baker video game *Foldit* and Flower's "new media" model.

Discussions in the breakout section on "using engineering education research findings to inform curricular innovation" included general support for the view that in order for education and technical research findings to more effectively inform curricular innovation, engineering educators should create virtual communities that establish collaborative links[17] among and between education researchers, classroom innovators, and traditional engineering faculty. This could be accomplished, for example, through wikis (i.e., websites that can be collaboratively edited by multiple users) which contain information regarding the successes and failures of past and current educational techniques, or a globally accessible database of curricular innovations and promising educational models.

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[14] Sanders, Ted "U.S. Seeks a Nation of Learners For New Century," *Chicago Tribune*, December 17, 1996.
[15] From Just in Time Teaching at http://jittdl.physics.iupui.edu/jitt/what.html [Accessed May 6, 2009].
[16] Monaghan, Peter. "Due processors: Educators Seek a Digital Upgrade for Teaching Law." *Chronicle of Higher Education*, vol. 55, no. 8, (2008) page 10.
[17] Wegner, Etienne et al., "Cultivating Communities of Practice" Harvard Business School Press, 2002.

3

Specific Observations

Specific observations during the breakout sessions were recorded and grouped into the following themes: (a) the need to expand faculty and administrator communication networks, (b) the need to increase instructor incentives, and (c) the importance of developing more interaction with stakeholders. In the following section, the specific observations from the workshop are considered in context of one of these three themes.

EXPAND FACULTY AND ADMINISTRATOR COMMUNICATION NETWORKS

Most of the keynote and panel presenters urged engineering faculty and administrators to increase their levels of connectivity and communicative capacity within the field of engineering, as well as with other disciplines. The importance of communicating across disciplinary boundaries was heavily emphasized in Goldberg's presentation. Some workshop participants expressed the view that such moves were a prerequisite to meeting Vest's goal of reaping benefits from bridging the frontiers between micro-level systems, such as biological and nanotechnological, become bridged with macro-level systems, like energy, the environment, health care, and manufacturing. Options offered by various individuals as possible means to address this need include the following:

- A website detailing promising engineering practices drawn from across the globe could serve as a meso level (between the macro and micro levels) connector. While meetings and conferences occasionally gather engineering educators, researchers, and innovators together physically, an online presence would allow for the field to connect intellectually without temporal or geographic restrictions. A conceptual example is offered by the Peer Reviewed Research Offering Validation of Effective and Innovative Teaching (PR^2OVE-IT) web site[18].
- Social networking sites devoted to engineering education could facilitate the sharing of educational resources and innovations including providing a mechanism for users to become familiar with projects outside their individual specialties. Similar to the system used by social facilitation websites such as Facebook, those in the engineering community could seamlessly interact with others through networks based on professional society, research interests, geographic region, or any number of categories. Because of the popularity and ease of use of this technology, it would also appeal to domestic and international current or prospective engineering students. An example of such a site applied in a technical domain is Purdue's NanoHub[19].

[18] PR^2OVE-IT Peer Reviewed Research Offering Validation of Effective and Innovative Teaching http://www.pr2ove-it.org [Accessed May 6, 2009].
[19] nanoHub.org Online Simulation and More http://nanohub.org/ [Accessed May 6, 2009].

INCREASE FACULTY INCENTIVES

In their talks, Fromm, Bordogna, Flowers, Duderstadt, and Goldberg variously made the point that there is an on-going need for educational innovation, integration of research and education, and cross-disciplinary synthesis. During breakout section discussions, workshop participants generally agreed that much of the needed change was unlikely to occur unless faculty at all levels, including graduate students as future faculty, were provided with the incentives necessary for them to seriously engage in conducting education research as well as the scholarly teaching that translates education research and traditional engineering research into improved practice. Among the possible incentives identified by various individuals were the following:

- Explicit attention to education research, curricular innovation, and scholarly teaching in tenure and promotion criteria,
- Greatly expanded opportunities for grant funding for education-focused activities at NSF and other federal agencies including the education aspect of NSF's Faculty Early Career Development (CAREER) awards,
- Demonstrable institutional support, such as graduate student support and other allocations of internal funds, for education research, curricular innovation and scholarly teaching,
- Public recognition of institutional excellence in education research and curricular innovation such as that provided by the National Research Council rankings departments in terms of technical and scientific research, and
- Agreement that the ABET General Criterion 6 on faculty qualifications requires faculty demonstration of continuing attention to their instructional skills (e.g., regular participation in professional development activities).

ENHANCE INTERACTIONS AMONG STAKEHOLDERS OF ENGINEERING EDUCATION

In their remarks, Orsak, Bordogna and Duderstadt placed great emphasis on the need to broadly engage the stakeholders of engineering education including faculty and administrators, employers, and students. Some workshop participants expressed the view that engineering education could be improved through more regular and structured interaction among these groups. Ideas offered by individual participants included the following:

- Actively engage undergraduate and graduate students as collaborators in educational innovations. Olin College very effectively did this in the design of its curriculum.

- Rather than engaging in episodic cycles of "reform," adapt a purposeful engineering approach of research, development, and innovation to the process of engineering education.
- Resurrect a version of NSF's now-defunct Institution-wide Reform program that recognizes changes to entire engineering colleges that change and facilitate prize winners to communicate change with others.

Workshop participants were uniformly enthusiastic about the discussions held and hopeful that the engineering community could be stimulated to further the discussion in a variety of forums, while many might assert that we know what needs to be done and it's time to get on with it. In order to be made realizable, the broad themes offered above would have to be fleshed out within the context of individual engineering disciplines and on individual campuses where engineering faculty can take ownership and advance progress to achieving Vest's vision of engineering learning environments that are "exciting, creative, adventurous, rigorous, demanding, and empowering."

4

Next Steps

Presentations and discussions at the workshop offered insights helpful to understanding the content, scope, and sequence of current engineering curricula as well as the competing pressures and aims that make sweeping changes to engineering curricula difficult to achieve. They also offered many constructive ideas on ways to move forward toward achieving learning experiences that would better prepare engineering students to thrive in the challenging engineering practice environments envisioned for the 21st Century. One potential next step identified by several individual workshop participants, but emphasized by organizing committee chair Eli Fromm of Drexel, was the need for academic leaders to take ownership of the premise of needed reforms and to develop implementable action plans.

Appendixes

A

Workshop Agenda

Engineering Curriculum Workshop: Understanding the Design Space

National Academy of Engineering: March 23rd - 24th, 2009

Day 1:

Plenary Session: (Lecture Room)

8:30 a.m. Opening Comments
Charles M. Vest: President, National Academy of Engineering

8:45 Comments of Organizing Committee Chair
Eli Fromm: Drexel University

9:00 Presentations by invited speakers with moderated discussion

Theme: How we arrived at the current curriculum
Joseph Bordogna: University of Pennsylvania

Theme: A stretch vision for engineering education
Woodie C. Flowers: Massachusetts Institute of Technology

10:15 Break

10:30 **Theme: Engaging students through grand challenges**
Geoffrey Orsak: Southern Methodist University

11:00 **Panel Discussion: Curricular implications of emerging trends in engineering:** 15-minute presentations followed by 30 minutes of moderated discussion

Theme: Engineering at the interfaces with other disciplines
David Goldberg: University of Illinois at Urbana-Champaign

Theme: The engineer's role in a global economy
Norman Fortenberry: National Academy of Engineering

Theme: The engineer's role in developing countries
Benjamin Linder: Olin College

Theme: Teaching leadership within engineering
Lesia Crumpton-Young: National Science Foundation

12:30 p.m. LUNCH

Breakout Sessions:

1:30 Overview of breakout sessions and expected outcomes

1:45 **Breakout sessions (identifying barriers and enablers to innovation)**

A. Engineering education research findings that inform curricular innovation (Lecture Room)
Led by *Barbara Olds*, Colorado School of Mines

B. Models of enacted curricular innovation efforts and their lessons learned (Board Room)
Led by *Stan Napper*, Louisiana Tech

C. Working with non-engineering faculty to achieve breadth and depth in engineering education innovation (Room 180)
Led by *Deborah Hughes Hallett*, University of Arizona

3:45 Break

4:15 Report back from Breakout Groups
10 minutes per group to allow for Q &A

5:00 Adjourn Day 1

Day 2:

Plenary Session: (Lecture Room)

9:00 a.m. Summary of Day 1

9:15 Presentation by invited speaker with moderated discussion

Theme: Using the liberal arts model as a template for engineering education
James J. Duderstadt: University of Michigan

Breakout Session: (Board Room, 180)

10:15 **Breakout sessions (overcoming barriers to innovation, developing implementation strategies, and identifying information resource needs)**

Workshop Agenda

Engineering Curriculum Workshop: Understanding the Design Space

National Academy of Engineering: March 23rd - 24th, 2009

<u>Day 2</u>:

11:30	Breakout groups report back 15 minutes per group
12:30 p.m.	Adjourn – Closing comments from *Eli Fromm*

B

Workshop Participants

Susan Ambrose
Carnegie Mellon University

Kurt Becker
Utah State University

Robert Beichner
North Carolina State University

Joseph Bordogna
University of Pennsylvania

Beth Cady
National Academy of Engineering

Debra Chachra
Olin College of Engineering

Lesia Crumpton-Young
National Science Foundation

Ryan Davison
National Academy of Engineering

Elliot Douglas
University of Florida

James Duderstadt
University of Michigan

Woodie Flowers
Massachusetts Institute of Technology

Adam Fontecchio
Drexel University

Norman Fortenberry
National Academy of Engineering

Patricia Fox
American Society for Engineering Education

Eli Fromm
Drexel University

David Goldberg
University of Illinois at Urbana-Champaign

Doug Gorham
IEEE

Robert Gustafson
Ohio State University

Deborah Hughes-Hallet
University of Arizona

P.K. Imbrie
Purdue University

Nathan Kahl
National Academy of Engineering

Sherra Kerns
Olin College of Engineering

Benjamin Linder
Olin College of Engineering

Donald McEachron
Drexel University

Stan Napper
Louisiana Tech University

Wendy Newstetter
Georgia Institute of Technology

Jim O'Brien
American Society of Civil Engineers

Barbara Olds
Colorado School of Mines

Geoffrey Orsak
Southern Methodist University

Tom Perry
American Society of Mechanical Engineers

Russ Pimmel
National Science Foundation

Teri Reed-Rhoads
Purdue University

Gloria Rogers
ABET

Larry Shuman
University of Pittsburgh

Allen Soyster
National Science Foundation

Harriet Taylor
National Science Foundation

Alan Tucker
SUNY Stony Brook

Linda Vanasupa
California Polytechnic State University

Charles Vest
National Academy of Engineering

Robert Warrington
American Society of Mechanical Engineers

Jeannette Wing
National Science Foundation

C

Biosketches of Organizing Committee Members and Rapporteur

Eli Fromm, C*hair,* is the Roy A. Brothers University Professor, Professor of Electrical and Computer Engineering, and Director of the Center for Educational Research in the College of Engineering of Drexel University. He has been Principal Investigator of a number of bioengineering research projects involving implantable transmitters and sensors, Principal Investigator of the Drexel E^4 educational reform project and of the Gateway Engineering Education Coalition. His academic leadership positions have included Vice President for Educational Research, Vice Provost for Research and Graduate Studies, and interim Dean of Engineering at Drexel. He has also held positions with the General Electric and Dupont companies, the Science Committee of the U.S. House of Representatives as a staff member and Congressional Fellow, Program Director at NSF, and Visiting Scientist with the Legislative Office of Research Liaison of the Pennsylvania House of Representatives. He is a fellow of the IEEE and the AIMBE, a recipient of awards and honors from IEEE, ASEE, ABET, Smithsonian Institution, Drexel University, and is the inaugural recipient of the Bernard M. Gordon Prize from the National Academy of Engineering. Professor Fromm was elected to the National Academy of Engineering in 2004

Woodie C. Flowers is the Pappalardo Professor Emeritus of mechanical engineering at the Massachusetts Institute of Technology. His specialty areas are engineering design and product development. His current research includes work on the creative design process and product development systems. He helped create MIT's renowned course "Introduction to Design." Flowers received national recognition in his role as host for the PBS television series Scientific American Frontiers from 1990 to 1993 and received a New England EMMY Award for a special PBS program on design. He is a Fellow of the American Association for the Advancement of Science and recipient of an Honorary Doctor of Humane Letters from Daniel Webster College. He was recently selected to receive a Public Service Medal from NASA and the Tower Medallion from Louisiana Tech University. At MIT, he is a MacVicar Faculty Fellow, an honor bestowed for extraordinary contributions to undergraduate education. He was also the inaugural recipient of the Woodie Flowers Award by FIRST, a national organization that promotes youth involvement in science and technology. Currently, Flowers is a director of four companies and is on the board of Technology Review magazine. He is a member of the Lemelson-MIT Prize Board Executive Committee, is National Advisor and Vice Chairman of the Executive Advisory Board for FIRST; and is a member of the Historical Commission in Weston, Massachusetts. Professor Flowers was elected to the National Academy of Engineering in 1994.

Sherra Kerns is F. W. Olin Distinguished Professor of Electrical and Computer Engineering, founding Vice President for Innovation and Research at the F. W. Olin College. Kerns came to Olin from Vanderbilt University, where she was a senior faculty member and held various posts, including Chair of the Department of Electrical and Computer Engineering and Director of the multi-disciplinary, multi-institutional

University Consortium for Research on Electronics in Space. A Fellow of the IEEE, Kerns is the recipient of IEEE's prestigious Millennium Medal and the IEEE Education Society's Harriet B. Rigas Award. Kerns has also received many awards for outstanding undergraduate teaching, and has been very active nationally in promoting engineering education. She has been named to the Advisory Committee for the National Academy of Engineering's Center for the Advancement of Scholarship on Engineering Education and the Steering Committee for the NAE Engineer of 2020 Phase II: Engineering Education in the New Century initiative. She is the Past President of the American Society for Engineering Education (ASEE), the nation's premier society for technical education and is a Fellow of the ASEE. She also serves as an Executive Committee member of the Engineering Accreditation Commission of ABET, the accreditation body for engineering programs in the U.S. At Olin College, she is pioneering a unique administrative position with responsibility for enhancing faculty intellectual vitality, providing opportunities for students to learn through discovery, and building a culture that rewards innovation and the taking of appropriate risks.

Lueny Morell is director of engineering education innovation at HP Labs. Her job entails working with the higher education community and leading academic institutions on everything from research and student recruitment to customer and government relations and policy advocacy. She is also involved in curriculum development, advising industry, facilitating accreditation initiatives, supporting student and faculty research, and philanthropic projects. Before joining HP in 2002, Professor Morell had a 24-year career at the University of Puerto Rico, where she held various positions, both at the Mayaguez Campus (UPRM) and the system level. A full professor of chemical engineering, she was director of the UPRM Research and Development Center, a member to the Academic Senate and Administrative Board, and special assistant to the chancellor and dean of engineering in charge of strategic alliances, new educational initiatives, and outcome assessment. Professor Morell also coordinated the ABET 2000 accreditation for UPRM. A licensed professional engineer and certified ABET evaluator, she has done professional consulting work and is a member of many professional and honorary societies, including Tau Beta Pi, Phi Kappa Phi, Sigma Xi, Alpha Delta Kappa, American Society of Electrical Engineers, and American Institute of Chemical Engineers. Professor Morell has more than 40 scientific and educational papers to her credit and has received many honors during her academic career.

Teri Reed-Rhoads is Assistant Dean of Engineering for Undergraduate Education and Associate Professor in the Department of Engineering Education at Purdue University. In addition, she is director of the institute for P-12 engineering research and learning (INSPIRE). Reed-Rhoads' teaching interests include engineering statistics, quality engineering and introductory freshman engineering courses. Her research interests include statistics education, concept inventory development, assessment and evaluation of learning and programs, recruitment and retention topics, diversity, equity, and P-12 engineering education outreach. She has received funding from a number of National Science Foundation programs, the Department of Education, various foundations, and industry. She is an active participant in the American Society for Engineering Education, the American Educational Research Association, and the Institute of Electronics and

Electrical Engineers as well as being a member of the Institute of Industrial Engineers and the American Statistical Association.

Alan Tucker is Distinguished Teaching Professor and Undergraduate Director in the Department of Applied Mathematics at Stony Brook University. He has been at Stony Brook since 1970, serving as chair or undergraduate program director for over 30 years. His research specialty is graph theory. He has been active in a range of educational studies and reports by the Mathematical Association of America and American Mathematical Society, serving as project director in several. His links to engineering include membership on the Advisory Committee of the NAE Center for Advanced Study in Engineering Education and locally at Stony Brook serving as chair of the Executive Committee of the College of Engineering and Applied Sciences for the past 10 years.

Ryan C. Davison is a Christine Mirzayan Science and Technology Policy Fellow with the National Academies. He earned a PhD in behavioral neuroscience from the University of Alabama at Birmingham in May 2007. His graduate research implemented a sophisticated form of electrophysiology which allowed for the activity patterns of single neurons in non-anesthetized, behaving primates to be measured. As a post-doctoral Fellow at the Smith-Kettlewell Eye Research Institute, he characterized the visual system by implanting strain gauges and muscle force transducers in extraocular muscles in order to better understand the relationship between motor neuron firing rates and muscle contractile forces. His Fellowship with NAE allowed him to promote public awareness of critical science and engineering issues and learn a great deal about engineering education curricula. He is a voracious consumer of political information and currently pursuing a career in science education policy.