# Implementing the Recommendations of the 5xME Workshop

Report from a workshop sponsored by the

National Science Foundation

(Grant # CMMI 0855698)

Edited by A.Galip Ulsoy and Kon-Well Wang

http://umich.edu/~ulsoy/5XME.htm

*"Appearance every decade of a definitive report on the future of engineering education is as predictable as the sighting of the first crocuses in spring."*

*- Bill Schowalter*

Lake Buena Vista, Florida

November 12-14, 2009

*"Scientists discover the world that exists;*

*Engineers create the world that never was."*

*- Theodore Von Karman*

## Executive Summary

A workshop, sponsored by the National Science Foundation (NSF Grant # CMMI 0855698), was held on November 12-14, 2009 in Lake Buena Vista, Florida. The goal of this workshop was to work towards implementation of the recommendations for transformative change in mechanical engineering education that came from the earlier *5xME Workshop* (held May 2007). As stated in that original workshop: *The challenge for engineering schools in the USA is how to educate a mechanical engineer that provides five times the value added when compared to the global competition, i.e., the "5xME."*

Thirty invited participants, with interest and expertise in mechanical engineering education, took part in this *Implementing the Recommendations of the 5xME Workshop*. Plenary presentations were given by Sheri Sheppard (Stanford University), Jim Dudersatdt (University of Michigan), Warren Seering (Massachusetts Institute of Technology), Adnan Akay (Carnegie Mellon University and Bilkent University) and Galip Ulsoy (University of Michigan). During breakout sessions held at the workshop, the participants outlined several mechanical engineering curricula consistent with the workshop goal. These are presented in detail in Section 3 of this report. Although, it was not a goal of this workshop to arrive at a consensus among the participants, nevertheless, it became clear during the workshop discussions that several concepts were widely adopted in outlining the sample curricula in Section 3. We note those concepts here as general recommendations:

1. Graduates of our mechanical engineering curricula pursue a wide variety of careers, and curricula should be sufficiently flexible to prepare them accordingly.
2. A professional (or design) "spine" in the curriculum, that offers engineering reasoning, engineering synthesis and other professional skills during all four years, is needed, rather than just a senior capstone design experience.
3. There was general agreement on the topics that constitute the fundamentals of mechanical engineering (see Section 3), and general agreement that only a first course should be required in each of those topics. Further study in each being delegated to electives.
4. There was general agreement that engineering grand challenges can provide motivating themes for the projects in the professional/design spine.

Furthermore, the workshop participants recommended that the National Science Foundation fund further studies along two distinct directions. First, analytical studies that help us to better understand the design of a mechanical engineering curriculum, and second synthesis studies, or pilot implementations of curricular reform based on our current knowledge of these issues. Examples of both types of studies are given in Section 4 of this report.

The materials (e.g., report, plenary presentations) from this workshop, as well as from the previous 5xME workshop, can be downloaded as PDF files from the 5xME workshops web site:

http://umich.edu/~ulsoy/5XME.htm

# 1. Introduction

This report is a summary of the workshop held November 12-14, 2009 in Lake Buena Vista, Florida in conjunction with the American Society of Mechanical Engineers (ASME) International Mechanical Engineering Congress and Exposition (IMECE). The report was edited by A. Galip Ulsoy and Kon-Well Wang, based upon input from all the workshop participants. That input was collected during the workshop itself; from the breakout sessions and during the morning of the final day. Also, a draft of the report was circulated for comment to all workshop participants before being finalized by the editors.

The workshop, entitled *Implementing the Recommendations of the 5xME Workshop* was sponsored by the National Science Foundation (NSF) under grant CMMI 0855698. The goal of this workshop was to work towards implementation of the recommendations for transformative change in mechanical engineering education that came from the earlier *5xME Workshop* (held May 2007).

As described in detail in Section 2 of this report, this workshop was organized by a planning committee and included approximately 30 invited participants who are recognized leaders in mechanical engineering education (e.g., department heads, undergraduate program advisors, education researchers). Five plenary presentations (see the Appendix) set the stage for the workshop activities. The participants then broke up into four groups and discussed and answered questions that had been posed by the workshop planning committee. These discussions led to the outlines of several sample curricula, which are summarized in Section 3 of this report. It was not the intent that workshop participants reach a consensus on curricula that implement the recommendations of the *5xME Workshop*. Rather that they offer the outline of several curricula that take step (small or large) in that direction. Nevertheless, the workshop participants did agree on some broad recommendations, and identified needs for further research. These are summarized in Section 4 of this report.

**Background**

The National Science Foundation (NSF) sponsored a workshop, held May 2007, and entitled *The "5xME" Workshop: Transforming Mechanical Engineering Education and Research in the USA*. The ambitious goal of the workshop was to lay the foundation for transformative change in mechanical engineering (ME) education. The workshop was motivated by the fact that the science-based engineering education taught at our engineering schools has become a commodity, available to students all over the world, including low-wage markets. Global companies employ such world-class engineering talent, often at 20% of the cost in the USA, and are moving manufacturing, analysis, design and even research/development activities to such locations.

*The challenge for engineering schools in the USA is how to educate a mechanical engineer that provides five times the value added when compared to the global competition, i.e., the "5xME."* The workshop report (see http://umich.edu/~ulsoy/5XME.htm) includes the following recommendations:

1. In today's global knowledge economy, mechanical engineers educated in the USA must be able to add significantly more value than their counterparts abroad, through the breadth of their intellectual capacity, their ability to innovate, and their leadership in addressing major societal challenges.
2. The bachelors degree should introduce engineering as a *discipline*, and should be viewed as an extension of the traditional liberal arts degree where education in natural sciences, social sciences and humanities is supplemented by education in the discipline of engineering for an increasingly technological world.
3. This bachelors degree in the *discipline* of engineering can be viewed as the foundational stem upon which several extensions can be grafted: (1) continued professional depth through a professional masters degree in engineering, and (2) transition to non-engineering career paths such as medicine, law, and business administration.

4. The masters degree should introduce engineering as a *profession*, and become the requirement for professional practice. This is where educational institutions and professional societies can build an awareness of the profession, as opposed to producing graduates who view themselves merely as employees.
5. Doctoral education in engineering is essential to national prosperity, and global competition is rapidly increasing. The doctoral degree in engineering, while indisputably the best in the world, needs to be enhanced and strengthened with an emphasis on breadth as well as depth, linking discovery and innovation, and improved leadership and teaching skills.
6. Lifelong learning programs in engineering, including executive education, need to be developed and delivered to engineers at all stages in their professional development.

A follow-up NSF-sponsored workshop, was held in conjunction with the American Society of Mechanical Engineers (ASME) International Mechanical Engineering Congress and Exposition (IMECE) on November 12-14, 2009 in Orlando, Florida, and focused on *Implementing the "5xME" Workshop Recommendations*. Specifically developing the structures, or outlines, of ME curricula that would embody some or all of these recommendations. The proposed ME curricula developed at this follow-up workshop will then be disseminated via the AMSE Vision 2030 session at the ASME International Mechanical Engineering Education Conference (IMEEC) to be held in March 25-27, 2010, and through the activities of the ASME Vision 2030 education committee. It is also expected that various institutions will pursue pilot programs to demonstrate and assess the proposed curricula, in part through proposals submitted to the NSF.

It has been well-established that graduates of our current ME programs follow many diverse career paths. Ten years after graduation ME graduates are not only practicing mechanical engineering, but a many will actually be pursuing careers outside of mechanical engineering practice, such as technology management, business, medicine, or law. Many of our graduates will at some point hold positions of leadership in engineering organizations, often by serving as technical managers. Mechanical engineering graduates will be particularly well suited for such positions because of the breadth of their knowledge and their problem solving skills. We must begin to view such technical managers to be mechanical engineers who are in leadership positions, not as graduates who used to be mechanical engineers. When graduates of ME degree programs serve as technical managers they are indeed still mechanical engineers.

Not all these graduates utilize all the knowledge they acquire during their degree program. However, some of the knowledge imparted is consistently used for all career paths, e.g., engineering principles, problem formulation and solution, design, and innovation. Recommendations 2 and 3 above, from the 5xME Workshop, are aimed at addressing this reality by calling for an engineering and technology focused liberal arts degree. Such a degree would provide a strong foundation for students who will practice mechanical engineering, typically after also completing a professional practice oriented maters degree. This new bachelors degree, focused on the discipline of engineering, would not only cover the very core and fundamental mechanical engineering courses in good depth, emphasize problem formulation/solution, design, innovation, entrepreneurship and creativity, but would develop the breadth of the student's intellectual capacity by considering engineering and technology in its broader societal and environmental context. Furthermore, those graduates of this new bachelors degree who choose not to practice mechanical engineering will have a foundation in engineering that will serve them well in our increasing technologically sophisticated society.

Such a curriculum, focused on the discipline of engineering, by providing a flexible foundation for all types of students, will also address recruitment, diversity and retention issues that many mechanical engineering programs are currently faced with. Students have diverse talents and abilities that need to be nurtured, and allowed to develop. Such a curriculum can help to attract not only students who are fascinated by technology, but also students who are motivated by the positive societal impact that those technologies can have. Studies have shown that this is especially true with groups traditionally underrepresented in engineering, such as women and minorities. A bachelor's degree in

engineering, which emphasizes innovation and creativity, collaboration, project-based education and the societal impact of technology also provides an excellent foundation for a professional masters degree in mechanical engineering. Such professional graduate schools in engineering, similar to those in medicine and law, can work closely with industry and elevate the prestige of engineering as a profession.

The transformation needed in mechanical engineering education must embrace societal priorities, and become an exciting and attractive leadership opportunity for a diverse pool of talent from all segments of our society. Such a transformation will require a new infrastructure, and new methods of educational delivery, that develop the specific abilities of diverse students, to achieve the attributes that graduates must possess, e.g.:

1. Broad grounding in fundamentals, focusing on science, technology as well as its societal and corporate context, will enable students to provide leadership within their organizations in an increasingly technological world.
2. Flexibility and agility will lead to motivated learners who pursue topics based upon their interests and special abilities, attracting and retaining the best and brightest.
3. Project-based mechanical engineering education will develop the creative aspects of engineering, including problem formulation/solution, design and innovation.
4. Post-baccalaureate professional schools of engineering, working closely with industry and emphasizing professional practice, will transform engineering into a true learned profession comparable in rigor, prestige and influence to medicine and law.

The implementation of such transformative changes to mechanical engineering education can provide value to both our students (i.e, create the 5xME) and contribute to the competitiveness and prosperity of the nation.

### Purpose and Scope

This report summarizes the activities and outcomes of the *Implementing the Recommendations of the 5xME Workshop*. This first section provides an overview and background. Section 2 is a description of the workshop, including the planning, participants, agenda, and a description of the breakout sessions. Section 3 describes the curricular outlines that were developed by the breakout groups during the workshop. Broad recommendations and research needs are identified in Section 4, and Section 5 includes some Concluding Remarks. This report also includes a list of references and an Appendix summarizing the plenary presentations at the workshop.

## 2. Workshop Description

### Planning Committee

The workshop was organized by a planning committee consisting of the following individuals:

- Adnan Akay, Carnegie Mellon and Bilkent Universities
- Norman Fortenberry, National Academy of Engineering
- John Linehard, Massachusetts Institute of Technology
- Sheri Sheppard, Stanford University
- Gretar Tryggvason, Worchester Polytechnic Institute
- Galip Ulsoy, University of Michigan
- Kon-Well Wang, University of Michigan

This committee met on Thursday August 28, 2009 at the Westin hotel at the Detroit Metropolitan airport, and roughed out the workshop format, agenda, invitees, speakers, breakout tasks, etc.

**Workshop Participants**

The participants who attended the workshop are listed in Table 1, and include three NSF representatives, the plenary speakers, and 25 additional participants. Many of the participants are department heads, or undergraduate program advisors, and represent a variety of mechanical engineering programs (e.g., private vs. public, small vs. large). The participants brought tremendous knowledge, experience, energy and passion to the workshop discussions, and were the key to a successful workshop.

**Table 1. List of Workshop Participants With Their Affiliations and Contact Information.**

| | Surname | Name | Organization | E-mail |
|---|---|---|---|---|
| 1 | Akay | Adnan | CMU | akay@bilkent.edu.tr |
| 2 | Duderstadt | Jim | Univ. of Michigan | jjd@umich.edu |
| 3 | Enelund | Mikael | Chalmers | mikael.enelund@chalmers.se |
| 4 | Ferreira | Placid M. | Univ. of Illinois | pferreir@illinois.edu |
| 5 | Ge | Ping | NSF | pge@nsf.gov |
| 6 | Goekner | Matthew | UT Dallas | *goeckner@utdallas.edu* |
| 7 | Hirleman | Dan | Purdue | e.daniel.hirleman.1@purdue.edu |
| 8 | Jayasuriya | Suhada | NSF | sjayasur@nsf.gov |
| 9 | Kirkpatrick | Allan | CSU | allan@engr.colostate.edu |
| 10 | Kortshagen | Uwe | Univ. of Min. | uk@me.umn.edu |
| 11 | Kulacki | Frank | Univ. of Min. | kulacki@me.umn.edu |
| 13 | Laursen | Tod | Duke | laursen@duke.edu |
| 14 | McKenna | Ann | NSF | amckenna@nsf.gov |
| 15 | Mendelsohn | Dan | OSU | mendelsohn.1@osu.edu |
| 16 | Predebon | William | MTU | wwpredeb@mtu.edu |
| 17 | Prinz | Fritz | Stanford | fbp@cdr.stanford.edu |
| 18 | Rencis | Joseph J. | Univ. of Arkansas | jjrencis@uark.edu |
| 19 | Rotea | Mario | UT Dallas | rotea@utdallas.edu |
| 20 | Seering | Warren | MIT | seering@mit.edu |
| 21 | Sheppard | Sheri | Stanford | sheppard@stanford.edu |
| 22 | Smith | Dick | RPI | smithr@rpi.edu |
| 23 | Srinivasan | Krishnaswamy | OSU | srinivasan.3@osu.edu |
| 24 | Sundararajan | Siriam | Iowa State Univ. | srirams@iastate.edu |
| 25 | Thole | Karen | PSU | kthole@engr.psu.edu |
| 26 | Townsend | Jessica | Olin | jessica.townsend@olin.edu |
| 27 | Tryggvason | Gretar | WPI | gretar@WPI.EDU |
| 28 | Ulsoy | Galip | Univ. of Michigan | ulsoy@umich.edu |
| 29 | Wang | Kon-Well | Univ. of Michigan | kwwang@umich.edu |
| 30 | Warrington | Bob | MTU | row@mtu.edu |
| 31 | Wei | Stan | Cooper Union | swei@cooper.edu |
| 32 | Wepfer | Bill | Ga. Tech. | bill.wepfer@me.gatech.edu |
| 33 | Whitworth | H.A. | Howard Univ. | hwhitworth@howard.edu |

**Workshop Agenda**

The agenda for the workshop was drafted at the planning meeting, and then finalized by Galip Ulsoy and Kon-Well Wang. It is given below. The workshop was held at the Dolphin Hotel, Disney World resort, Lake Buena Vista, Florida.

**Thursday 11/12 – Oceanic 1, Lobby Level**

6:30pm Reception and dinner

After dinner presentation:

"A peak into the engineering student experience (and implications for educational practices)," Sheri Sheppard, Stanford University

**Friday 11/13 – Oceanic 3, Lobby Level**

7:30am *Continental breakfast*

8:00am Welcome and introductions

8:15am Plenary talks

"A 21st Century Paradigm for U.S. Engineering"

Jim Duderstadt, University of Michigan

"Meeting the Customers' Needs with a Curriculum,"

Warren Seering, MIT

10:30am *Break*

11:00am Plenary talks

"Shaping an Ideal Mechanical Engineer's Education"

Adnan Akay, Bilkent University and Carnegie Mellon University

"Implementing the Recommendations of the 5xME Workshop,"

Galip Ulsoy, University of Michigan

Noon Breakouts to answer questions (see below)

12:30pm *Lunch*

2pm Breakouts to outline curricula (see below)

3pm *Break*

3;30pm Resume breakout sessions to outline curricula

4:30pm Report back from breakout sessions

5pm *Adjourn (evening free)*

**Saturday 11/14 – Oceanic 3, Lobby Level**

7:30am *Continental Breakfast*

8am Prepare outline of report, including outlines of sample curricula

11:30am Wrap up discussion, next steps

Noon *Adjourn*

**Breakout Groups**

The afternoon of Friday 11/13 consisted of breakout sessions. The four groups for the breakout sessions are listed below. Each group has a designated facilitator (F) to moderate discussions, and to help keep them focused on the breakout topics. The questions posed for the breakout sessions are given below. Also, each group has a designated recorder and reporter (R) who takes notes, and reports back to the larger group after the breakout sessions. In each case the facilitator was a member of the planning committee, and the recorder/reporter was not.

**Group A**

Kon-Well Wang (F)

Uwe Kortshagen (R)

Jim Duderstadt

Matthew Goekner

Dan Mendelsohn

Sheri Sheppard

Robert Warrington

Stan Wei

Suhada Jayasuriya

**Group B**

Galip Ulsoy (F)

Mario Roteo (R)

Placid Ferreira

Tod Laursen

Dick Smith

Karen Thole

Bill Wepfer

H.A. Whitworth

**Group C**

Adnan Akay (F)

Fritz Prinz (R)

Mikael Enelund

Dan Hirleman

Allan Kirkpatrick

Jessica Townsend

Warren Seering

Ann McKenna

**Group D**

Gretar Tyggvason (F)

C. Srinivasan (R)

Frank Kulacki

Joseph Rencis

William Predebon

Siriam Sundararajan

Ping Ge

**Questions for Breakout Sessions**

Included in the recommendations of the 5xME Workshop are the following key points:

1. The bachelors degree should introduce engineering as a *discipline*, and should be viewed as an extension of the traditional liberal arts degree where education in natural sciences, social sciences and humanities is supplemented by education in the discipline of engineering for an increasingly technological world.

2. This bachelors degree in the *discipline* of engineering can be viewed as the foundational stem upon which several extensions can be grafted: (1) continued professional depth through a professional masters degree in engineering, and (2) transition to non-engineering career paths such as medicine, law, and business administration.

3. The masters degree should introduce engineering as a *profession*, and become the requirement for professional practice. This is where educational institutions and professional societies can build an awareness of the profession, as opposed to producing graduates who view themselves merely as employees.

Morning breakout session: In the context of the recommendations from the 5xME Workshop, please answer the following:

1. What are the 5 subjects central to an ME curriculum (excluding prerequisites)?
2. What are 5 subjects, from disciplines outside of ME, which should be in the curriculum (excluding prerequisites)?
3. What are the 5 key professional skills that should be in the ME curriculum?
4. Identify 5 subjects in a typical ME curriculum that are not essential.
5. What is the role of project-based learning in the ME curriculum?
6. How do current and emerging technologies influence student learning and curricular content?
7. What are the major constraints on developing a new ME curriculum (e.g., accreditation, finance, job market, duration)?

Afternoon breakout session: In the context of the recommendations from the 5xME Workshop, each breakout group is asked to tackle one of the following tasks:

A. Assuming a blank slate, describe the content of the recommended bachelors degree plus maters degree
B. Given our current curriculum, plan a transitional curriculum (bachelors and masters) that will move towards this goal
C. Alternatively, starting with a blank slate, plan a 4-year bachelors curriculum (rather than a bachelors plus masters) that achieves the same goals.

Note that it is the structure and outline of a curriculum (i.e., prerequisites, subjects to be included), rather than the full details (e.g., courses, credits, etc.) that we are looking for.

# 3. Curriculum Outlines

**Group A (as reported by Uwe Kortshagen and Kon-Well Wang)**

Morning breakout session: In the context of the recommendations from the 5xME Workshop, please answer the following:

1. What are the 5 subjects central to an ME curriculum (excluding prerequisites)?

a) Materials
b) Design & Manufacturing
c) Thermo Fluids
d) Mechanics
e) Systems

2. What are 5 subjects, from disciplines outside of ME, which should be in the curriculum (excluding prerequisites)?

a) Art
b) Electronics
c) Social Science
d) Biology
e) Ethics
f) Business

3. What are the 5 key professional skills that should be in the ME curriculum?

a) Information Technology
b) Problem formulating and solving
c) Communication skills
d) Experimental skills
e) Teamwork and Leadership

4. Identify 5 subjects in a typical ME curriculum that are not essential.

Anything beyond 1st core ME classes

5. What is the role of project-based learning in the ME curriculum?

a) Student Engagement (one of several engaging pedagogies)
b) Approximation of Practice
c) Problem solving
d) Gaining depth
e) Subject Integration

6. How do current and emerging technologies influence student learning and curricular content?

6.1. Teaching technology (Facebook, Youtube, …)

a) Help engage students
b) Clickers: evaluate student learning

6.2. New Emerging Areas (Nano, Bio, Environment, …)

a) Currently not appreciated by alumni and industry

b) Selected topics (Energy) will engage students – impact on world, grand challenges

7. What are the major constraints on developing a new ME curriculum (e.g., accreditation, finance, job market, duration)?

a) Faculty buy-in
b) Resources (including faculty time/effort)
c) Faculty capability
d) One-time transition cost
e) Faculty reward system
f) Leadership
g) State Legislation

Afternoon breakout session: In the context of the recommendations from the 5xME Workshop, each breakout group is asked to tackle one of the following tasks:

A. Assuming a blank slate, describe the content of the recommended bachelors degree plus maters degree.

See Figure 1 below.

a) 25% Basic Science and Math
b) 25% Problem Solving and Design
c) 25% Social Science (Arts, Business, …)
d) 25% Engineering Principles

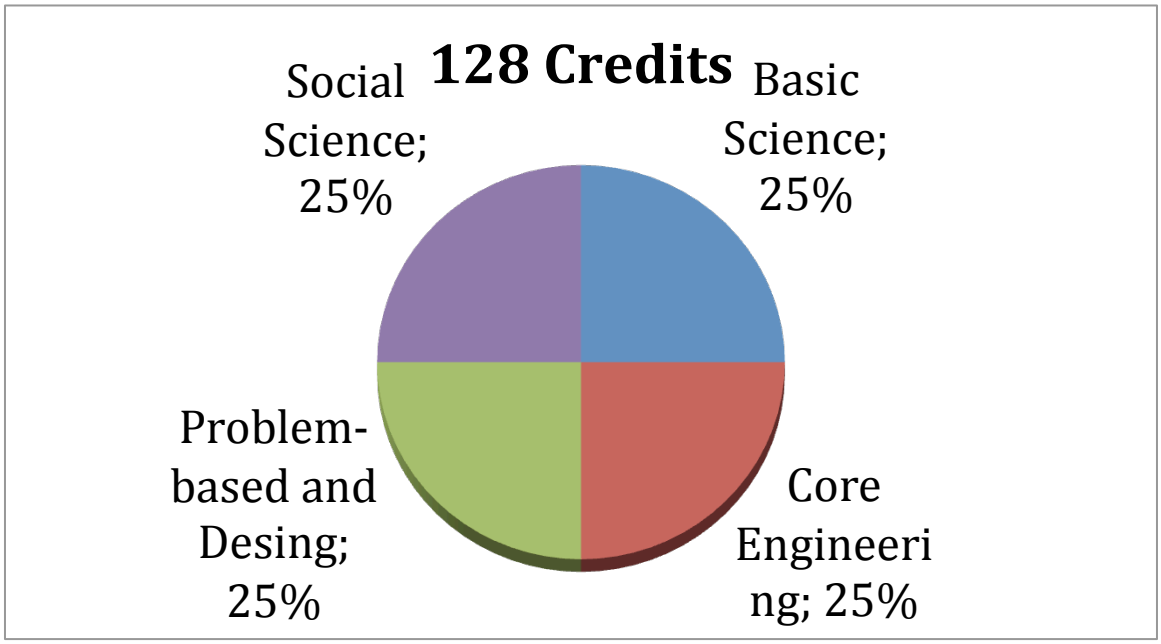


Figure 1. Group A "Blank Slate" Curriculum for BS Level

a) 25% Basic Science and Math (8 classes)
   - 4 Math
   - 2 Physics
   - 1 Chemistry
   - 1 Biology
b) 25% Problem Solving and Design (8 classes)
   - Inverse Engineering

- Design concepts
- Systems engineering
- Case studies
- Modeling and Simulation
- Research based classes
- 2 Capstone

c) 25% Engineering Principles (8 courses)
- 1 Mechanics
- 1 Electronics
- 1 Transport
- 1 Materials
- 1 System and Controls
- 1 Instrumentation & Basic Measurements & Human interface
- 2 Elective

d) 25% Social Science (Arts, Business, …)
- Arts
- Humanity
- Business
- Economics
- Cultural Diversity
- Communication
- Interpersonal Psychology
- Elective

<u>1 year Prof. Masters</u>

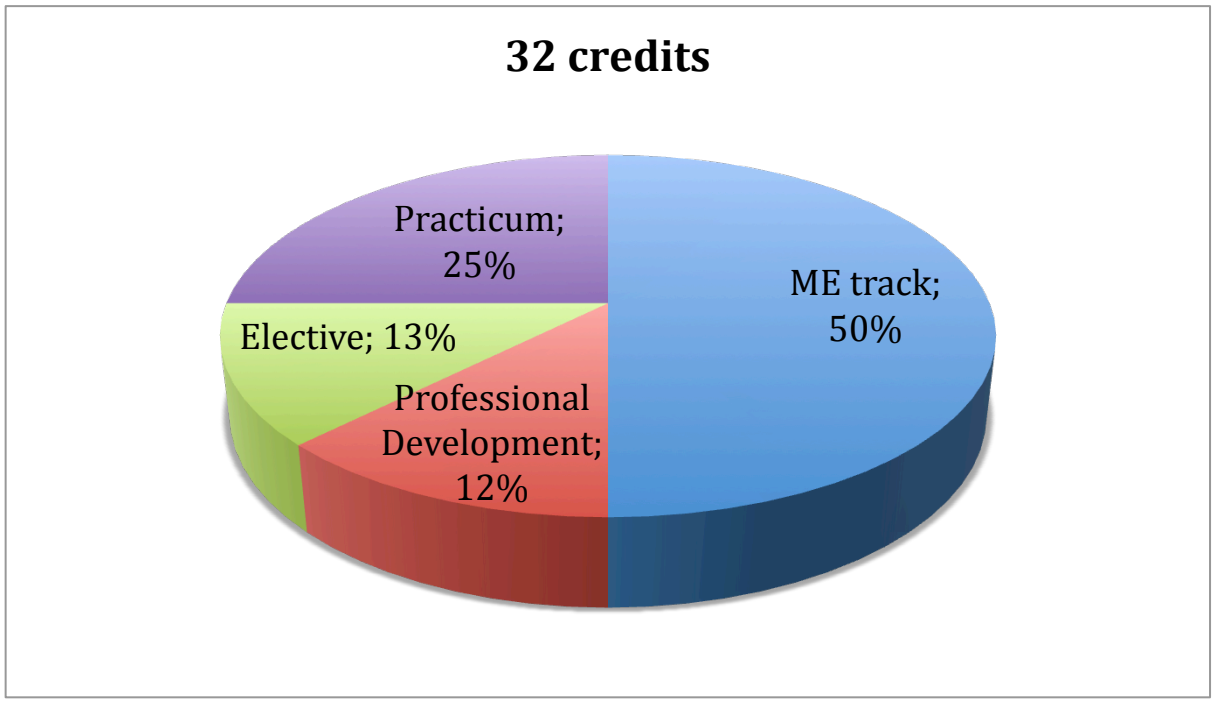


Figure 2. Group A "Blank Slate" Curriculum for MS Level

a) ME core (in tracks, 1 out of 5, 4 classes each)
- Adv. Mechanics

- Fluids/Thermal
- Materials
- Design & Manufacturing
- Systems & Controls

b) 1 Global Engineering, Entrepreneurship, Leadership
c) 1 Elective
d) 2 Practicum (Team, Management, Innovation)

5xME certification should be provided to the student at the end of the program.

C. Alternatively, starting with a blank slate, plan a 4-year bachelors curriculum (rather than a bachelors plus masters) that achieves the same goals.
   a) Same BS program as under A, however, 25% problem-based/design content will focus on ME topics
   b) 25% Problem Solving and Design (8 classes) focusing on mechanical systems
      - Inverse Engineering
      - Design concepts
      - Systems engineering
      - Case studies
      - Modeling and Simulation
      - Research based classes
      - 2 Capstone

**Group B (as reported by Mario Rotea and Galip Ulsoy)**

Afternoon breakout session: In the context of the recommendations from the 5xME Workshop, each breakout group is asked to tackle one of the following tasks:

A. Assuming a blank slate, describe the content of the recommended bachelors degree plus maters degree.
   - Paradigm shift to incorporate mechanisms for shaping students based on their interest/passion by *mass customization* and for motivating the students by incorporating *grand challenges*.
   - Have a *professional/design spine* that runs from the first to the last year. To build engineering tools and skills, teamwork, communication, etc.
   - Have a "Taylor series expansion approach" where *levels of engineering confidence and competence are established as the student progresses through the curriculum*. Thus, the student can discuss and demonstrate her/his engineering competence at each level via the professional/design spine and grand challenges course.
   - Have a mega course (i.e., design spine with a grand challenge topic) in the *first year* where a *grand challenge* incorporates main topics from ENG, PHY/CHM/BIO, MATH, and the like. Teach this course in a *coordinated* fashion, e.g. using instructors or TAs from engineering in the science and math courses. First year complementary coursework would also include humanities/social science base.
   - Have a mega course in the *2nd year* with focus on the use of ME knowledge and skills in grand challenge problem. Cover ME fundamentals in complementary coursework.
   - *Year 3* mega courses focus on various subareas of ME. Complementary coursework would include ME and non-ME elective topics (shaped via distribution requirements).
   - *Year 4* mega courses are customized to interests of small student teams. Complementary coursework would include technical and no-technical elective topics (shaped via distribution requirements).
   - Co-curricular and internship activities are highly encouraged throughout (maybe even required, or better integrated in some way?)

**Group C (as reported by Fritz Prinz and Warren Seering)**

Morning breakout session: In the context of the recommendations from the 5xME Workshop, please answer the following:

1. What are the 5 subjects central to an ME curriculum (excluding prerequisites)?

Thermo

Solids/Structure

Dynamics

Mechanical Design

Transport Phenomena

Control Theory

Problem solving skills

Thermo Fluids

Product Realization

Systems/Informatics

Mechanics

Systems thinking
Engineering Problem formulation Solving

Design

Systems Engineering (tuned for ME)

2. What are 5 subjects, from disciplines outside of ME, which should be in the curriculum (excluding prerequisites)?
   a) Quantum mechanics
   b) Biology
   c) Leadership
   d) Communication
   e) Business/entrepreneurship
   f) Arts

3. What are the 5 key professional skills that should be in the ME curriculum?
   a) Ethics
   b) Teamwork
   c) Cross-cultural Communication

d) Project Management
e) Leadership
f) Problem definition/solving

4. Identify 5 subjects in a typical ME curriculum that are not essential.

All follow-on courses are unnecessary

All course offerings can be valuable

5. What is the role of project-based learning in the ME curriculum?

a) Projects create a context for learning
b) Teamwork and communication skills become critical
c) Integrates and connect to larger scale societal problems which helps diversity
d) Platform for learning of fundamentals

6. How do current and emerging technologies influence student learning and curricular content?

a) Virally by transforming traditional courses
b) Increased student-teacher communication via wireless technology
c) Personal Response Systems
d) Computer Graphics/Visualization of complex systems

7. What are the major constraints on developing a new ME curriculum (e.g., accreditation, finance, job market, duration)?

a) Faculty of 2020
b) Interface with other departments
c) Accreditation
d) Diffuse the Engineering Tribal Identity

**Group D (as reported by Cheena Srinivasan)**

Morning breakout session: In the context of the recommendations from the 5xME Workshop, please answer the following:

1. What are the 5 subjects central to an ME curriculum (excluding prerequisites)?
   a) Mechanics
   b) Thermo-fluids
   c) Manufacturing and materials
   d) Design
   e) Systems

2. What are 5 subjects, from disciplines outside of ME, which should be in the curriculum (excluding prerequisites)?
   a) Electrical sciences

b) Biology
c) Mathematics
d) Chemistry
e) Physics
f) Business/management & economics

3. What are the 5 key professional skills that should be in the ME curriculum?
   a) Communication and interpersonal skills
   b) Innovation and entrepreneurial skills
   c) Critical and analytical thinking
   d) Hands-on skills
   e) Leadership and strategic thinking
   f) Ethical behavior
   g) Learning/Ability to Learn

4. Identify 5 subjects in a typical ME curriculum that are not essential.
   a) Advanced or second course in ME
   b) Less mathematics (to the extent that it is not embedded in the ME curriculum)
   c) Less humanities

5. What is the role of project-based learning in the ME curriculum?
   Projects that incorporate/introduce/enhance the following are essential to integrating technical and humanistic skills
   a) Integration of knowledge from across the curriculum
   b) Ability to use new knowledge including just-in-time knowledge
   c) Teamwork
   d) Product realization

6. How do current and emerging technologies influence student learning and curricular content?

   6A. (Potential) Influence of current technologies on learning and content
   a) More extensive simulations
   b) Individualized/customized learning
   c) Student ability to live in world where knowledge is communal
   d) Cyber-enabled learning communities

   6B. (Potential) Influence of emerging technologies on learning and content
   a) Should be integrated in curriculum to a greater extent
   b) Students learn to view BS degree as beginning
   c) Offer more opportunity for interdisciplinary work
   d) Results in greater scientific/technical literacy

7. What are the major constraints on developing a new ME curriculum (e.g., accreditation, finance, job market, duration)?
   a) K – 12 preparation
   b) Fiscal resource allocation under responsibility-based budgeting
   c) Faculty reward structure not conducive
   d) Faculty cohesiveness of purpose

Afternoon breakout session: In the context of the recommendations from the 5xME Workshop, each breakout group is asked to tackle one of the following tasks:

Where are we going? (We have at least two paths: i) develop a bachelor's degree establishing engineering as a *discipline* followed by a professional master's degree, and ii) work within the current four-year degree structure

A. Assuming a blank slate, describe content of recommended bachelor's degree and professional master's degree in ME

   a) Topics A/C on agenda
   b) Assumptions
   c) BSME: 4 year, 120 (semester) credits
   d) Masters: 1 yr, 30 credits

Recommended curriculum

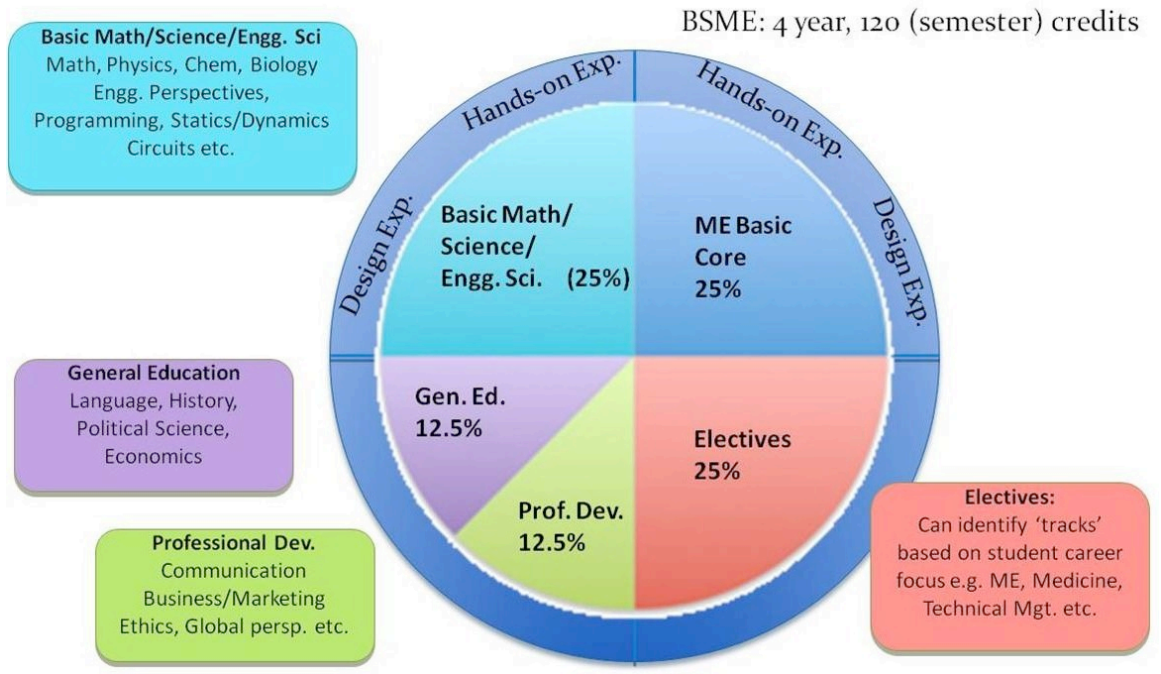


Figure 3 Group D "Blank Slate" Curriculum for BS Level

Major changes from current

- Increased focus on professional development
- Streamlining humanities/social sciences requirements into general education
- ME focus on basic core requirements rather than multiple course sequences
- Client (student)-oriented by increasing elective content to allow tailoring towards multiple careers in addition to traditional mechanical engineering practice
- Programs can provide more specificity in electives if desired

Professional Masters Degree (1 year)

a) 1 yr, 30 credits (~ 10 courses)
b) Provide advanced training for immediate impact upon entering profession
c) Technical Core (5-7) courses
d) Advanced technical topics in ME/Eng. Sciences/Math
e) Programs can tailor further specifics
f) Allow flexibility for student to tailor degree experience
g) Professional Development (3-4 courses)
h) Topics related to Business/Language/Law etc. that enhanced professional's non-technical competency in context of engineering profession
i) Allow flexibility for student to tailor degree experience
j) Industry-driven project experience (1-2 courses)
k) The professional practice equivalent of a research-based thesis

# 4. Recommendations and Research Needs

It was not a goal of this workshop to arrive at a consensus among the participants, but rather to develop outlines of several sample curricula that would take us closer to the ideas recommended in the original 5xME Workshop of May 2007. This workshop has succeeded in that goal, and the sample curricula generated in the breakout sessions have been presented in Section 3 of this report.

Nevertheless, it became clear during the workshop discussions that several concepts were widely adopted in outlining these sample curricula. We note those here as general recommendations:

1. Graduates of our mechanical engineering curricula pursue a wide variety of careers, and curricula should be sufficiently flexible to prepare them accordingly.
2. A professional (or design) "spine" in the curriculum, that offers engineering reasoning, engineering synthesis and other professional skills during all four years, is needed, rather than just a senior capstone design experience.
3. There was general agreement on the topics that constitute the fundamentals of mechanical engineering (see Section 3), and general agreement that only a first course should be required in each of those topics. Further study in each being delegated to electives.
4. There was general agreement that engineering grand challenges can provide motivating themes for the projects in the professional/design spine.

Furthermore, the workshop led to discussions of research studies needed to better understand the relationship between our curricular decisions, and the educational outcomes experienced by our students. Inspired by the MIT study described in the plenary talk by Warren Seering, the workshop participants recommended further such studies. The workshop participants strongly encourage the NSF to fund such studies, in two categories, as listed below:

1. <u>Analysis Studies to Achieve Better Understanding:</u>
   a) Case studies of successful engineers (what content was useful, needed, contributed to their success yrs 1-12) also for doctors/lawyers with engineering background?
   b) Study how students best learn (sociology, psychology, cognitive sciences), to help understand students thinking and choices during their experience?
   c) How do we inspire and promote creativity, and innovation, while maintaining rigor, in our students?
   d) Are we overloading the design courses with too many objectives (e.g., not only design, but communications, teamwork, etc.)?
   e) Appropriate metrics for continuous and systematic improvement of engineering programs?
   f) Study similar to Seering's for K-12 education to see why students do not choose engineering?

g) Extend the Seering study (not only 30 year olds) to 25 year, etc. olds, and throughout their professional life?
h) How do we scale up effective small pilots?

2. Synthesis Studies to Move Forward Based Upon What We Currently Know
   a) Introduce engineering knowledge in K-12 (currently, no standards)
   b) Four year professional/design spine
   c) Forum (collaborative network?) for sharing information about innovations in engineering education? Teachengineering.com? ASME education journal? Design Engineering (International Design Society)?
   d) Organize curricula around grand challenges?
   e) Teaching of fundamental limits in engineering as the basis for a curriculum?
   f) Develop professionalism in our approach to teaching (build into PhD programs)?

# 5. Concluding Remarks

This day and a half workshop was interesting, engaging, and exciting. The plenary speakers provided thoughtful and provocative points of view. The participants brought considerable knowledge, expertise and passion to the workshop tasks and discussions. This report cannot do justice to the many inspired ideas and engaging discussions that took place.

The task of transformative reform in our mechanical engineering curricula (which are already world-class by most measures) is truly a daunting one. Thus, the task tackled by this workshop, and the previous 5xME workshop, is most challenging. Is it indeed possible to achieve "five times" (or even "two times") the value added, over our current curricula (which are rapidly becoming commodities available to students all over the world)? An important insight from this workshop is that by carefully studying how our graduates view their educational experience, in terms of the contribution of specific curricular components to their professional career, we can do much (5x? 2x?) better in designing our curricula. It is our professional obligation to do so.

If we are indeed convinced that we can do better, then how can this agenda for transformative reform in mechanical engineering education be moved forward? Again, this is a most difficult challenge. Certainly, creating a forum for discussion of such ideas, as this workshop has done, will be helpful. Many of the participants are in positions to lead change in their own institutions, and may find the ideas and discussions in the workshop encouraging of such reform. Support from the NSF for proposals that will pilot, and asses and disseminate, such reforms at various institutions would be very valuable. Also, it is clear that further "analysis" of , and "experimentation" within, our current educational programs, through studies such as those recommended in Section 4 above, will help improve our understanding, and consequently help us to design better mechanical engineering curricula. The NSF can play a vital role in supporting such studies. Finally, several participants in the workshop are involved in broader society-wide efforts at mechanical engineering education reform through the ASME Vision 2030 task force, and its upcoming report. The ASME Vision 2030 report, and plenary session at the March 25-27, 2010 International Mechanical Engineering Education Conference in Long Beach, can help to engage a broader group in these important discussions of how to improve our mechanical engineering curricula.

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# 7. Appendix - Plenary Talks

This Appendix contains very brief summaries of the plenary presentations from the *Implementing the Recommendations of the 5xME Workshop*. The complete plenary presentation slides, for each talk, can be directly downloaded from the 5xME web site as PDF files. The web site is:

http://umich.edu/~ulsoy/5XME.htm

**Sheri Sheppard, *Insights from Studies of the Undergraduate Engineering learning Experience*.**

This talk summarizes several studies of undergraduate education, and considers pathways into engineering, pathways through engineering, and pathways out of engineering. It sheds light on recruitment, retention, what motivates students, comparison of engineering students to those in other disciplines, the need for a professional spine, and many other issues.

**Jim Duderstadt, *Engineering for a Changing World*.**

Considers engineering as both a discipline, and a profession, and compares it to other professions, especially medicine. Argues for emphasis on engineering as a discipline at the bachelors level, as part of a broad liberal arts education. Emphasizes professional engineering education at the masters level.

**Warren Seering, *A Curriculum that Meets the Customers' Needs*.**

Presents the results of a study of MIT mechanical engineering alumni. Focuses on what students do 10-12 years after graduation. Broadly, they fall into three equal sized groups: (a) engineers, (b) managers, and (c) other (e.g., doctors, lawyers, artists). Examines what they use from their undergraduate education. This varies widely based on the individual, but all seem to use the engineering reasoning and professional skills from their design courses.

**Adnan Akay, *Shaping an Ideal Mechanical Engineer's Education*.**

Identifies the essentials for a mechanical engineering education. Emphasizes the differences among students: their multiple intelligences and cognitive abilities. Considers how the changing world (and changing technologies) affect a mechanical engineering education. Presents a new mechanical engineering curriculum being developed at Bilkent University.

**Galip Ulsoy, *Implementing the 5xME Recommendations*.**

Summarizes *The 5xME Workshop: Transforming Mechanical Engineering Education and Research in the USA* (May 2007) and its recommendations. Presents the goals, agenda, and breakout activities for this workshop on implementing the recommendations of the original 5xME workshop.