APPENDIX A

LYLE H. SCHWARTZ: BIOGRAPHY

Lyle Schwartz is a Senior Research Scientist with the Department of Materials Science and Engineering at the University of Maryland. He was professor of materials science and engineering at Northwestern University for 20 years and director of Northwestern's Materials Research Center for five of those years. He then became director of the Materials Science and Engineering Laboratory at the National Institute of Standards and Technology (NIST) where he served for more than 12 years. His experience there included metals, ceramics, polymers, magnetic materials, techniques for characterization, and standardization of these characterization techniques, and operation of the NIST nuclear research reactor. He shared the responsibilities of management of the NIST facilities as a member of the executive board. Schwartz left NIST to become president of AUI, the management organization responsible at that time for the Department of Energy's Brookhaven National Laboratory and the National Science Foundation's National Radio Astronomy Observatory. During this brief period, he acted as interim director of Brookhaven during a complex period of transition to new management. Schwartz subsequently assumed responsibility for basic research on structural materials of interest to the U.S. Air Force in addition to the areas of propulsion, aeromechanics, and aerodynamics. He completed his government service as director of the Air Force Office of Scientific Research with responsibility for the entire basic research program of the Air Force. His current interests include government policy for R&D, particularly for materials R&D, materials science education at K–12 and university levels, and enhanced public understanding of the roles and importance of technology in society. He is a member of the National Academy of Engineering. He is the immediate past chair of the ASM International Materials Education Foundation and is an honorary member of ASM International, and a member of TMS and the Materials Research Society. Schwartz received both his B.S. in engineering and Ph.D. in materials science from Northwestern University.

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APPENDIX B

NMAB WORKSHOP, IRVINE, CALIFORNIA, OCTOBER 2002

Workforce and Education in Materials Science and Engineering: Is Action Needed?

Students today face a very different world when they graduate with a degree in materials science or engineering. The types and numbers of jobs, the various methods of networking, and the interfaces between materials and other disciplines have all changed dramatically over the past 30 years. Behind these changes are other transformations in the structures of departments at universities, the visibility of materials in both the research and production-based worlds, and the perception of materials to the public.

To explore some of these issues, a workshop entitled, "Workforce and Education in Materials Science and Engineering: Is Action Needed?" was hosted by the National Materials Advisory Board at the Beckman Center of the National Academies in Irvine, California, on October 21, 2002. Substantial audience participation took place throughout the event, with a final discussion period devoted to the question, "Is Action Needed?" The general theme revolved around the basic issue of whether the United States has the right number, mix, and quality of materials scientists and engineers to meet current and future demands. At the outset, it was emphasized—and this was amply confirmed by the final discussion—that the workshop would not and could not provide complete answers to the questions posed, but would rather relate to the nominally simpler question, "Is There a Problem?".

Defining Materials Science

Reza Abbaschian (University of Florida) presented comprehensive statistics that in summary showed the following:

- Materials science and engineering (MSE) is a highly fragmented discipline and is small compared to other engineering sub-disciplines
- The discipline itself is difficult to define with extremely blurred boundaries
- An integrated educational curriculum is hard to achieve except in the largest MSE departments, and the constraints on the number of units that can be taught and poor high school preparation do not allow breadth and depth
- There are substantial issues in integrating the polymer component in metals and ceramics oriented curricula (i.e., contrary to the expectations at the beginning of the MSE era)
- Recruitment of women (but not minorities) is reasonably successful
- At best there is a plateau in both students and funding
- The discipline is poorly represented in large part due to an excess of competing professional societies, most of which are not doing well financially.

Rustum Roy (Pennsylvania State and Arizona State Universities) followed with an inspirational message that sought to convey the notion that materials engineering and science was in fact the central discipline of our current scientific-cum-technology oriented century. But, as is obvious, this is not yet universally recognized and a necessary aim of our discipline is to convey this message to the uninitiated. In general, the materials community has done a poor job of public relations.

Steven Wax (Defense Advanced Research Projects Agency) presented the following important points from a government perspective:

- Although federal support of MSE is still large there is an increasing trend toward funding related physical sciences to the detriment of traditional MSE
- The importance of interdisciplinarity cannot be overemphasized
- For example, MSE should be playing a larger role in the biological area

Wax suggested that in the future the materials community needs to better identify and define areas to which they can contribute.

Demand for Materials Science and Engineering

Tom Hartwick presented the following basic statistics:

- The number of MSE degrees is at best constant but is probably decreasing (a recurring theme of the workshop was the difficulty of interpreting and relying on small number statistics with few definitive trends)

- There are modest demand increases in certain fields (service, in particular)
- Most materials scientists enter research, although only ~1/3 of those who desire to enter academia do so
- There is a relatively sharp decrease in demand for metals/ceramics educated graduates which must be related to the decrease in these manufacturing industries in the U.S. and their growing preference for off-shore locations
- Overall the number of U.S. citizens in the MSE educational pipeline is decreasing; the number of foreign students is increasing

Merrilea Mayo (National Research Council) concurred and elaborated on many of the above points and also emphasized that MSE graduates are sought after in management roles. In the ensuing discussion these themes were reiterated and amplified giving on the whole a rather downbeat assessment of the field. Harvey Schadler pleaded for a more outward attitude; MSE must work together towards common global goals to be effective.

Supply of Materials Scientists and Engineers

Julia Weertman (Northwestern University) surveyed available educational statistics (generally poor) from high school to doctoral levels and again pointed to a somewhat declining picture (except perhaps for Ph.D.s); quality (as measured by standard criteria) was also an issue at higher levels.

Gordon Geiger (Arizona) presented a further overview of the field including demand showing in some detail the startling decrease in employment at metallurgically-related laboratories and the overall workforce in the United States.

Is Action Needed?

The discussion on "Is Action Needed?" attempted to synthesize all the data, anecdotes and views presented at the workshop. It was clear the field has an identity crisis, in that the boundaries are not apparent and the needs and roles of materials scientists are not clearly defined. The overarching question posed at the meeting, namely "Does the U.S. have the right number, mix, and quality of materials scientists and engineers to meet current and future demands?" remains unanswered.

To enable us to understand the issues, the community can ask the following further questions:

- Can we get better, more inclusive, and more reliable data?
- How can we better identify ourselves and our field?
- How can we provide focus for the MSE educational curriculum?

APPENDIX C

SURVEY OF MATERIALS DEPARTMENTS COMPILED BY P. DAVIES FOR THE FALL UMC MEETING, NOVEMBER 2009

U.S. Independent MS&E Departments with Undergrad Programs (46) (ABET accredited except as noted)

Alfred University
Boise State University
California Polytechnic State University[a,b]
Carnegie Mellon University
Case Western Reserve University
Clemson University[a]
Colorado School of Mines[a]
Cornell University
Drexel University
Georgia Institute of Technology
Iowa State University
Lehigh University
Michigan Technological University
University of Missouri–Rolla
Massachusetts Institute of Technology
Montana Tech of the University of Montana[a,b]
New Mexico Institute of Mining and Technology
North Carolina State University
Northwestern University
Ohio State University
Pennsylvania State University
Purdue University[a]
Rensselaer Polytechnic Institute
Rutgers University
South Dakota School of Mines & Technology
Stanford University[c]
Johns Hopkins University
University of Alabama–Birmingham
University of Alabama–Tuscaloosa[a]
University of Arizona
University of California–Berkeley
University of California–Los Angeles
University of Florida
University of Idaho[b]
University of Illinois–Urbana-Champaign
University of Maryland
University of Michigan
University of Pennsylvania
University of Tennessee
University of Texas–El Paso[a]
University of Utah
University of Virginia[c]
University of Washington
University of Wisconsin–Madison
University of Wisconsin–Milwaukee[b]
Virginia Polytechnic Institute and State University

[a] Materials Engineering; [b] no Ph.D. program; [c] no ABET accreditation

U.S. Independent Materials Departments: Graduate Only (6) (no ABET accreditation)

State University of New York–Stony Brook
University of California–Santa Barbara
University of Delaware
University of North Texas
University of Texas at Arlington
University of Texas at Dallas

Chemical Engineering & Materials Science Departments (11) (ABET accredited except as noted)

San Jose State University
Stevens Institute of Technology[c]
University of California–Davis
University of California–Irvine
University of Cincinnati

University of Connecticut
University of Kentucky
University of Minnesota
University of Nevada–Reno
University of Southern California[c]
Wayne State University[c]

[c] no ABET accreditation

Mechanical Engineering & Materials Science Departments (6) (ABET accredited except as noted)

Duke University[c]
Rice University[c]
University of Denver[c]
University of Pittsburgh
Washington State University
Wright State University

[c] no ABET accreditation

MS&E Grad “Programs” (4) (no ABET accreditation)

California Institute of Technology
University of California–San Diego
University of Dayton
Vanderbilt University

Civil and Materials Engineering Departments (1)

University of Illinois at Chicago[c]

[c] no ABET accreditation

Mechanical, Aerospace, Chemical & Materials Departments (1)

Arizona State University

Mechanical, Materials & Aerospace Engineering Departments (1)

Illinois Institute of Technology

Materials Programs Offered through Other Engineering Departments (10)

Auburn University (Mechanical Engineering)
Brown University (Division of Engineering)
Columbia University (Applied Physics & Applied Mathematics)[c]
Michigan State University (Chemical Engineering and Materials Science and Mechanical Engineering)
Southwest Texas State University (Physics)[c]
University of Nebraska (Engineering Mechanics)[c]
Vanderbilt University (multiple)[c]
Worcester Polytechnic Institute (Mechanical Engineering)[c]
Winona State University[d]
Yale University (Mechanical Engineering)[c]

[c] no ABET accreditation; [d] Composite Materials Engineering

Polymer Science and Engineering (2)

Case Western Reserve University (Macromolecular Science & Engineering)
University of Akron (graduate only)[c]

[c] no ABET accreditation

Non-Engineering

University of Southern Mississippi (Polymers & High Tech Materials)
University of Massachusetts–Amherst (College of Natural Science, graduate only)

Materials Departments and Programs in the United States, 2009 vs. 1999

Category	**1999***	**2009**
Materials Specific Departments	17	2
Independent MSE Departments	49	52
Joint Departments	14	20
“Embedded” Programs	27	14
Total	**104**	**88**

* From Reference 10.

APPENDIX D

ABET ACCREDITED MATERIALS DEPARTMENTS 2009

University	Department Name	MSE	Materials	Met	Other
Materials Engineering					
The University of Akron	Mechanical-Polymer Engineering				1
University of Alabama at Birmingham	Materials Engineering		1		
Alfred University	Materials Science and Engineering	1			
Arizona State University	Materials Science and Engineering	1			
University of Arizona	Materials Science and Engineering	1			
Auburn University	Materials Engineering		1		
Boise State University	Materials Science and Engineering	1			
Brown University	Materials Engineering		1		
California Polytechnic State University	Materials Engineering		1		
University of California, Berkeley	Material Science and Engineering	1			
University of California, Davis	Material Science and Engineering	1			
	Electronic Materials Engineering				1
	Electrical Engineering/ Materials Sciences and Engineering				1
University of California, Irvine	Materials Engineering		1		
University of California, Los Angeles	Materials Engineering		1		
Carnegie Mellon University	Materials Science and Engineering	1			
Case Western Reserve University	Materials Science and Engineering	1			
	Polymer Science and Engineering				

University	Department Name	MSE	Materials	Met	Other
University of Cincinnati	Materials Engineering		1		
Colorado School of Mines	Metallurgical and Materials Engineering	1			
University of Connecticut	Material Science and Engineering	1			
Cornell University	Materials Science and Engineering	1			
Drexel University	Materials Engineering		1		
University of Florida	Materials Science and Engineering	1			
Georgia Institute of Technology	Materials Science and Engineering	1			
	Polymer and Fiber Engineering				1
University of Idaho	Materials Science and Engineering	1			
University of Illinois at Urbana-Champaign	Materials Science and Engineering	1			
Illinois Institute of Technology	Materials Science and Engineering	1			
Iowa State University	Materials Engineering		1		
The Johns Hopkins University	Materials Science and Engineering	1			
University of Kentucky	Materials Engineering		1		
Lehigh University	Materials Science and Engineering	1			
University of Maryland	Materials Science and Engineering	1			
Massachusetts Institute of Technology	Materials Science and Engineering	1			
Michigan State University	Materials Science and Engineering	1			
Michigan Technological University	Materials Science and Engineering	1			
University of Michigan	Materials Science and Engineering	1			
University of Minnesota	Materials Science and Engineering	1			
Montana Tech of the University of Montana	Metallurgical and Material Engineering		1		
New Mexico Institute of Mining and Technology	Materials Engineering		1		
North Carolina State University at Raleigh	Materials Science and Engineering	1			
Northwestern University	Materials Science and Engineering	1			
The Ohio State University	Materials Science and Engineering	1			
Pennsylvania State University	Materials Science and Engineering	1			
University of Pennsylvania	Materials Science and Engineering	1			
University of Pittsburgh	Materials Science and Engineering	1			
Purdue University at West Lafayette	Materials Science and Engineering	1			
Rensselaer Polytechnic Institute	Materials Engineering		1		
Rutgers, The State University of New Jersey	Materials Science and Engineering	1			
San Jose State University	Materials Engineering		1		
University of Tennessee at Knoxville	Materials Science and Engineering	1			
University of Texas at El Paso	Metallurgical and Materials Engineering		1		
University of Utah	Materials Science and Engineering	1			
Virginia Polytechnic Institute and State University	Materials Science and Engineering	1			
Washington State University	Materials Science and Engineering	1			
University of Washington	Materials Science and Engineering	1			
Winona State University	Composite Materials Engineering				1
University of Wisconsin-Madison	Materials Science and Engineering	1			
University of Wisconsin-Milwaukee	Materials Engineering		1		
Wright State University	Materials Science and Engineering	1			
Metallurgical Engineering					
The University of Alabama-Tuscaloosa	Metallurgical Engineering			1	
Missouri University of Science and Technology	Metallurgical Engineering			1	
University of Nevada-Reno	Materials Science and Engineering	1			
South Dakota School of Mines and Technology	Metallurgical Engineering			1	
University of Utah	Metallurgical Engineering			1	
Ceramic Engineering					
Alfred University	Ceramic Engineering				1
	Glass Engineering Science				1
Clemson University	Ceramic and Materials Engineering		1		
Missouri University of Science and Technology	Ceramic Engineering				1
Totals		**40**	**17**	**4**	**9**

* All data extracted from ABET web site: (www.abet.org/accredited_programs.shtml) by Lyle H. Schwartz on 11-28-2009. Included are all materials related departments accredited by ABET in the categories: Materials Engineering, Metallurgical Engineering and Ceramic Engineering. Excluded from this list are 13 departments categorized as Mining (or Mining and Mineral) Engineering. Also checked at this date were schools that did not show up in the three categories listed but had been listed as recently as several years ago in ASM Materials Handbook data. No existing materials related departments at these schools were on the accredited list. There may be materials related majors possible in other departments at these schools, but none have separate accreditation. (Private communication from Robert Snyder, head of the MSE department at Georgia Institute of Technology reveals that in 2010 the above listed Polymer and Fiber Engineering will be merged with the existing MSE department. At the same time, the University of Akron is creating and presumably will seek accreditation for a specialized degree in Corrosion Engineering.)

APPENDIX E

Ph.D. DISCIPLINES FOR FACULTY OF 15 TOP MSE DEPARTMENTS (percentages in parentheses)

Department	MSE	Metallurgy	Ceramics	Polymer	Physics	Chem	ME	EE	ChE	Other	Totals
CMU	12 (60)	3 (15)			3 (15)	1 (5)		1 (5)			20
Cornell	4 (23.5)			1 (5.9)	7 (41.2)	3 (17.6)				2 (11.8)	17
Florida	13 (38.2)	2 (5.9)		4 (11.8)	4 (11.8)	5 (14.7)		3 (8.8)	1 (2.9)	2 (5.9)	34
Illinois UC	8 (33.3)	2 (8.3)	1 (4.2)		7 (29.2)	5 (20.8)	1 (4.2)				24
Georgia IT	11 (20)	2 (3.6)	4 (7.3)	6 (10.9)	4 (7.3)	11 (20)	10 (18.2)	1 (1.8)	3 (5.5)	3 (5.4)	55
Michigan	14 (43.8)	2 (6.2)	1 (3.1)		6 (18.8)	5 (15.6)	1 (3.1)		1 (3.1)	2 (6.2)	32
MIT	14 (34.1)	4 (9.8)	1 (2.4)	2 (4/9)	8 (19/5)	1 (2/4)	3 (7.3)		2 (4/9)	6 (14/6)	41
Northwestern	11 (37.9)	3 (10.3)		1 (3.4)	9 (31)	3 (10.3)	1 (3.4)	1 (3.4)			29
Ohio State	13 (44.8)	8 (27.6)	1 (3.4)		3 (10.3)	1 (3.4)			1 (3.4)	2 (6.9)	29
U Penn	6 (26.1)	2 (8.7)		1 (4.3)	5 (21.7)	4 (17.4)	2 (8.7)		1 (4.3)	2 (8.7)	23
Penn State	13 (44.8)	1 (3.4)	2 (6.9)	1 (3.4)	1 (3.4)	7 (24.1)			4 (13.8)		29
Purdue	12 (57.1)	3 (14.3)			2 (9.5)	1 (4.8)	2 (9.5)		1 (4.8)		21
Stanford	10 (55.6)				4 (22.2)	2 (11.1)		1 (5.5)	1 (5.5)		18
Wisconsin	8 (40)	1 (5)			7 (35)		1 (5)		1 (5)	2 (10)	20
UC Berkeley	8 (32)	1 (4)		2 (8)	6 (24)	2 (8)	1 (4)			5 (20)	25
% Average	37.7	7.8	2.1	5.3	17.3	12.6	4.6	2.7	3.7	6.2	
"Average Department"	12	2.5	.7	1.7	5.5	4	1.5	.9	1.2	2	32

Data are summaries developed from the web sites of these 15 MSE departments (in a few instances aided by direct contact with departments) and compiled in the table. Departments selected are the same ones surveyed by Jones in his NSF Workshop presentation. The size distribution of these departments is displayed in the figure below. The data in this table represent faculty listed, not FTE. Thus, in some instances the "size" of the department may be greater than that counted by the department budget data. While there are three rather large departments (two at the Institutes of Technology), most are in the 20–30 range.

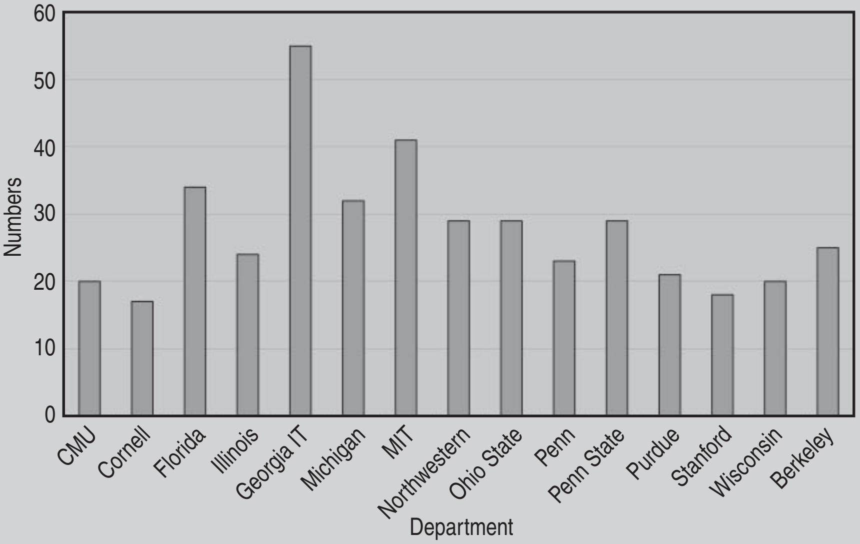


Figure 1. Faculty sizes of the top 15 MSE departments. Note that within these departments, only 15% cite degrees in Metallurgy, Polymers or Ceramics. While 38% have MSE degrees, many of these are certainly focused on technical activity other than structural materials (functional materials, "soft" materials, bio- and nano-materials, etc.). This is in stark contrast with the observation of COMSE that only 9% of the faculty interests were focused on non-structural materials. Also noteworthy is that more than 30% have degrees in chemistry, physics, or other sciences. [Further comments on this data may be found elsewhere in the body of this article, page 34, Current Technical Focus.]

APPENDIX F

EXCERPTS FROM "MATERIALS SCIENCE AND ENGINEERING – WHAT DO WE DO AFTER THE FIRST COURSE?" JOURNAL OF ENGINEERING EDUCATION (1979)

. . . To clarify what that background is, let me briefly refer to the requirements for a B.S. in Engineering at Northwestern. The list details the courses by name, but in brief includes one year (3 courses) of Chemistry including some P-Chem, one year (3 courses) of Physics, 2 years (6 courses) of calculus, 6 courses in introductory subjects in various engineering disciplines, 9 courses in the social sciences and humanities and only 16 courses in the departmental program. We have chosen to require that at least 11 of these be in the materials area, 9 of which are specified. The remaining 5 courses may be in materials also, but more commonly are in related, "support" areas including more Physics, Math, Chemistry, or for the Biomaterials majors, some selected courses in Biology. A typical arrangement of these specified courses is shown in Table F-1. The organization takes into account the fact that co-op students are in school for alternate quarters during their last 6 quarters, but to avoid complications, I've not shown that perturbation of the schedule. The 9 core courses will be the subject of my remaining remarks.

The first of these can be disposed of in short order. We teach a thermodynamics course which follows traditional lines (Table F-2). Lectures, reading, homework problems, and exams are the means of communication. Our students have all seen an introduction to the first and second laws of thermodynamics in Physical Chemistry in their second year (and a brief mention of them in Physics even earlier), so this is their third contact with these topics. Yet we repeat the origins of these concepts once again, feeling that repetition has value in this fundamental science. Concepts of enthalpy and entropy, and criteria for equilibria are emphasized. Phase equilibria in one component systems, the behavior of gases and reactions involving gases and pure condensed phases and a gaseous phase are treated. Only brief introduction to the statistical interpretation of entropy is given; however, this topic receives greater emphasis in later courses. A typical text used is that by D.R. Gaskell, Introduction to Metallurgical Thermodynamics. Students desiring more advanced topics on thermodynamics will find them in the non-required, senior and graduate level courses dealing with a) statistical thermodynamics and b) thermodynamics of solutions.

To continue with the course listing, I'll turn to 2 courses which follow the thermodynamics in subsequent quarters. Entitled Science of Engineering Materials, these courses cover some of the topics which might have been dealt with in a traditional course in Physical Metallurgy; however, with extensive applications to ceramic materials and some examples from polymers. (The students will all have had a full course on polymers prior to this—I'll return to that later.) The first course in this sequence covers the material shown in Table F-3. Phase diagrams are covered in some depth including a liberal sampling of ternary oxide systems. This material has been intentionally postponed until after the introductory thermodynamics, so that concepts of equilibrium can be dealt with in quantitative terms. Solution thermodynamics is introduced in this course and the ideas of ideal and non-ideal solutions discussed. Statistical thermodynamics is used to calculate the entropy of mixing in ideal solutions. The thermodynamic origin of phase diagrams from the free energy diagrams is discussed. Order-disorder is introduced. Non-equilibrium systems are considered in a quantitative way (e.g. segregation during solidification, zone refining, etc.). Point defects in solids are introduced and equilibrium concentrations calculated using concepts of the statistical origin of entropy. Diffusion is discussed from both a macroscopic and microscopic point of view, using concepts of point defect motion to derive Fick's first law. Laboratories include metallographic techniques, phase diagram determination in a simple eutectic system and diffusion of Sn into Fe studied metallographically. The choice of text here is still unresolved. Guy's Introduction to Materials Science (1972) and Ruoff's Materials Science (1975) have both been used with less than satisfactory results, each suffering from what I consider to be the fundamental problems with text books in our field. They all attempt to be all things to all men (and women). So many topics are covered in such minimal depth, that one must choose between superficiality and selective, instructor supplemented coverage. I usually opt for the latter, sending the students scurrying to find the material I've covered in class residing in some reserved book on the library shelf. Better books (for my purposes) would be Physical Metallurgy Principles (1964) by Reed-Hill and Introduction to Ceramics by Kingery (1976). But these suffer the obvious disadvantages that they are so specific to one material class that their use would defeat the intention of teaching a unified course.

In the second quarter of this two course sequence (Table F-4), kinetic behavior is developed in the areas of nucleation, crystal growth and kinetics of precipitation and order-disorder. Techniques of heat treatment, consideration of mechanical effects on metals and polymers and a brief treatment of amorphous materials complete this course. Lab projects include study of metals, inorganic and polymeric materials. Notably absent in this treatment, as well as in other courses, is an exhaustive consideration of the detailed transformation products in copper alloys, steels, aluminum alloys, titanium alloys, etc. Thus our graduates will certainly be deficient compared to those educated in the traditional metallurgical courses. They may take some time learning the metallurgy of steels if they should happen to be employed by the steel industry. However, we believe they will have the background to do this. More importantly, they will be prepared if it is a ceramics or polymeric industrial plant they enter.

Let me now return to the other major course taken in the first quarter of the junior year (Table F-5). This course deals exclusively with polymeric materials, emphasizing their solid state behavior including mechanical behavior, structure and phase transformations. The placement of this course in the first quarter of the major program was dictated by the relatively small amount of prerequisite material needed to handle this subject. In particular, general chemistry and the coverage of thermodynamics from P-Chem is sufficient. Laboratories for this course are just in the process of being developed, and have been included during the last two offerings of the course.

The senior year begins with one of the most demanding quarters the students take. In crystallography and diffraction (Table F-6) we have managed to include two courses into one time period and to treat the material at a rather advanced level. Diffraction has become a versatile tool in the characterization of engineering materials, and its study in conjunction with an introduction to crystallography is a major element in every author's treatment of Materials Science. Our approach at Northwestern is based on the belief that most applications of this technique demand a thorough understanding of the underlying principles. Our treatment of crystallography is based on developing an understanding of the wealth of information summarized in the International Tables of Crystallography. We begin diffraction theory with the development of reciprocal space because we feel that once mastered, this presentation makes possible the understanding of more complex problems. At the same time, we treat the physics of generation of useful radiation and methods of its detection. Naturally, once again, we found no text which treated this material just as we wished it were treated - but in this case we have responded - that is, Jerry Cohen and I have responded - and coauthored the text which we now use for this course (Diffraction from Materials (1978)).

A two quarter course on the physics of solids begins in the fall of the senior year. We have elected to treat this subject at the level of the book by Kittel, and consequently find it necessary to introduce several concepts in quantum mechanics which are not covered in the required physics courses which our students take (Table F-7). This course is, like the thermodynamics, rather conventional, and any one of several texts are acceptable. The course deals briefly with these topics in the first half, and then moves on to an examination of band structure and the applications of band structure to concepts in conductivity, magnetism, etc. The applications extend into the second quarter of the course (Table F-8) which is offered in the spring quarter due to time constraints dictated by the co-op program. This two quarter course is the last of our core courses without a formal laboratory. Many of the concepts of the course are demonstrated in class, and we have now submitted several proposals to fund laboratory equipment so that the students can get a hands-on feeling for electronic and magnetic behavior of materials.

The course on mechanical properties of materials is presented in the middle of the senior year (Table F-9), after the students have learned about phase transformations and crystallography. This allows us to treat such subjects as transformation of coordinates, solution and precipitation strengthening, and anisotropic mechanical behavior. Although a separate course on dislocation theory is taught for those (graduate students) who wish to emphasize mechanical properties, we introduce dislocation theory in this course as well. Coming as it does near the termination of the undergraduate student's academic experience, this course is expected to integrate much of the student's previous contact with materials structure with the manifestations of this structure in mechanical behavior.

Table F-1. Four-Year Program in Materials Science & Engineering

Junior Year			
Thermodynamics	Science of Engineering Materials I	Science of Engineering Materials II	
Polymer Science	X	X	
X	X	X	
X		X	X
Senior Year			
Diffraction from Materials Solid State Properties - I	Mechanical Properties	Solid State Properties-II Engineering Applications	
X	X	X	
X	X	X	

Table F-2. Applications of Thermodynamics

I. Introductory material
II. Definitions
III. Graphical and numerical methods of treating experimental data
IV. Reversible vs. irreversible processes
V. Second law
VI. Entropy
VII. Statistical thermodynamics
VIII. Helmholtz free energy
IX. Treatment of gas mixtures
X. Heterogeneous equilibria
XI. Behavior of solutions

Table F-3. Science of Engineering Materials-I

I. Micro- and macro-structure of materials
  A. Techniques of microscopy and metallography
  B. Introductory concepts in quantitative metallography
II. Phase diagrams in materials science
III. Thermodynamic origins of equilibrium diagrams
IV. Imperfections in solids
  A. Classification of point defects
  B. Derivation of equilibrium defect concentrations, rates of defect formation
  C. Techniques for study of point defects
V. Diffusion in solids

Table F-4. Science of Engineering Materials-II

I. Nucleation
  A. Interfacial energy
  B. Homogeneous nucleation
  C. Heterogeneous nucleation
  D. Grain boundary nucleation
II. Crystal growth
  A. Growth velocity
  B. Cellular growth; coring
  C. Dendrite growth; speculates
  D. Controlled solidification processes
III. Kinetics of phase transformation
  A. Aram theory
  B. Non-equilibrium effects
IV. Solid state transformations
  A. Precipitation hardening
  B. Order-disorder
  C. Spindle precipitation
V. Heat treatments
  A. Quenching effects on thermoplastics
  B. Quenching of steels
  C. TFT diagrams
  D. Annealing effects
  E. Sintering
VI. Mechanical effects of metals and polymers
  A. Strain hardening
  B. Forging, rolling, drawing
  C. Recovery, re-crystallization, grain growth
VII. Amorphous materials
  A. Silicates, and other inorganic
  B. Polymers; chain orientation effects
  C. Metallic glasses

Table F-5. Physical Properties of Polymers

I. Polymerization; the chain macromolecules; molecular architectures; molecular weight distributions; classification of polymeric materials, stereo-regularity
II. Chain-coiling statistics; macromolecular size; rubber networks and elasticity; viscoelasticity; the glass transition and the WLF equation; time-temperature superposition
III. Microstructure in crystalline polymer solids; nucleation and growth of chain-folded lamellar crystals, calorimetric analysis of crystalline and non-crystalline polymers
IV. Phase transformation kinetics. Deformation mechanisms in semi-crystalline polymers; textured polymer solids; annealing effects on lamellae and properties
V. Polymer alloys; graft copolymers; impact plastics
VI. Thermosetting resins; gelatin and vitrification; vulcanization
VII. Special properties: electrical; permeation
VIII. Compositing; polymer processing; fabrication methods
IX. Environmental effects; criteria for materials selection; failure analysis

Table F-6. Crystallography and Diffraction

I. Principles of crystallography
  A. One-, two-, and three-dimensional symmetry
  B. Use of the *International Tables of X-ray Crystallography,* Vol. I
  C. Some simple crystal structures
II. Geometric representations of crystals
  A. Miller indices
  B. Crystallographic calculations; the reciprocal lattice construction
  C. Graphical applications of crystallography
III. The nature of diffraction
  A. Diffraction from a grating, Braggs law
  B. The Ewald sphere and diffraction conditions
  C. Diffraction from a three dimensional structure
  D. Use of structure factor tables in the International Tables
IV. Properties of radiation
  A. Production of x-rays
  B. Interaction of x-rays with matter
  C. Absorption and fluorescence
  D. Detection of x-rays; film, counters and associated electronics
V. Recording the diffraction pattern
  A. Laue Patterns
  B. Rotating Crystal Method
  C. Diffractometer techniques
  D. Powder methods
VI. Determining crystal structures

Table F-7. Solid State Properties I

I. General introduction
II. Quantum states of atoms
III. The Schroedinger equation
IV. One electron in one square well
V. Many electrons in one square well
VI. One electron in two interacting square wells
VII. Two electrons in two wells
VIII. Many wells and energy bands
IX. Energy bands in solids
X. Crystal lattices - static properties
XI. Crystal binding - general
XII. Excitations
XIII. Lattice vibrations
XIV. Electrons in bands

Table F-8. Solid State Properties II

I. Review of semiconductor physics
II. Semiconductor devices
III. Superconductivity
IV. Diamagnetism
V. Paramagnetism
VI. Ferromagnetism
VII. Optical properties of insulators
VIII. Ferroelectricity
IX. Piezoelectricity

Table F-9. Mechanical Behavior of Solids

I. Definition of stress, strain
  A. Transformation of coordinate systems
  B. Relationship between stress and strain in elastic materials
II. Dislocation theory
  A. Discrepancy between theoretical and real strength of materials
  B. Description of dislocations
  C. Motion of dislocations and resultant atomic motion and strain
  D. Stress, strain, displacement fields around dislocations
  E. Self energy: straight dislocations, loops
  F. Forces acting on a dislocation; Peach-Koehler eqn. and applications useful for hardening mechanisms
  G. Tilt boundary
III. Theory of Strengthening mechanisms
  A. Solution hardening
  B. Precipitation hardening
  C. Strain hardening: single crystals, polycrystals
  D. Yield point phenomena
  E. Grain size effects
  F. Thermal activation effects of flow stress and strain rate
  G. Constitutive equations
  H. Strengthening mechanisms as applied to the design of a real material: nickel base super alloys
IV. Yield criteria: equivalent stress and plastic strain
V. Fracture
  A. Theoretical strength
  B. Griffith equation
  C. Brittle fracture
  D. Ductile fracture
  E. Fracture mechanics
VI. Fatigue
VII. Properties of several interesting materials: shape memory alloys; superplasticity alloys

APPENDIX G

CIVIL ENGINEERING BODY OF KNOWLEDGE

(Sources: Wikipedia and ASCE BOK 2nd Edition, 2008)

Current Status

In the United States, the body of knowledge necessary to obtain a license to practice engineering is defined by the laws or regulations of each state or territory. Most states currently have a standard that is a four step process. First, an individual must obtain a Bachelor's degree from a university program that is accredited by ABET. A two-step examination process administered by the National Council of Examiners for Engineering and Surveying must be completed. The first eight-hour test is the Fundamentals of Engineering exam; the second, also eight hours long, is the Principles and Practice of Engineering exam. The other step is to work an apprenticeship, usually of four years in length, under an already-licensed engineer. The second exam is generally the fourth and final step; the fundamentals exam can be taken before or after the apprenticeship in most states.

Many states now require continuing education to maintain a license to practice engineering. In 1979, Iowa became the first. Since then about half of the states have added continuing education to their engineering laws.

History

The American Society of Civil Engineers (ASCE) board of directors adopted a policy in 1998 (Policy Statement 465) that supported a change to make the master's degree be the first professional degree to enable practice of civil engineering. This proposed change was not widely accepted within the civil engineering profession and the policy was first revised in 2001 to support a requirement for a "master's degree or equivalent." It was revised again in 2004 to support "the attainment of a body of knowledge for entry into the practice of civil engineering at the professional level."

The ASCE board created a standing committee, the Committee on Academic Prerequisites for Professional Practice (CAP3), charged with the implementation of Policy Statement 465. CAP3 determined that the best implementation of PS 465 was to define the body of knowledge (BOK) that would form the foundation of the licensure process. CAP3 in turn established the Body of Knowledge Committee which wrote the first (2004) and second (current, 2008) versions of the BOK.

Content of the BOK

The body of knowledge defines 24 outcomes that make up the knowledge, skills, and attitudes necessary to practice civil engineering. The outcomes are divided into three categories: foundational, technical, and professional.

Foundational: 1. Mathematics • 2. Natural sciences • 3. Humanities • 4. Social sciences

Technical: 5. Materials science • 6. Mechanics • 7. Experiments • 8. Problem recognition and solving • 9. Design • 10. Sustainability • 11. Contemporary issues & historical perspectives • 12. Risk and uncertainty • 13. Project management • 14. Breadth in civil engineering areas • 15. Technical specialization

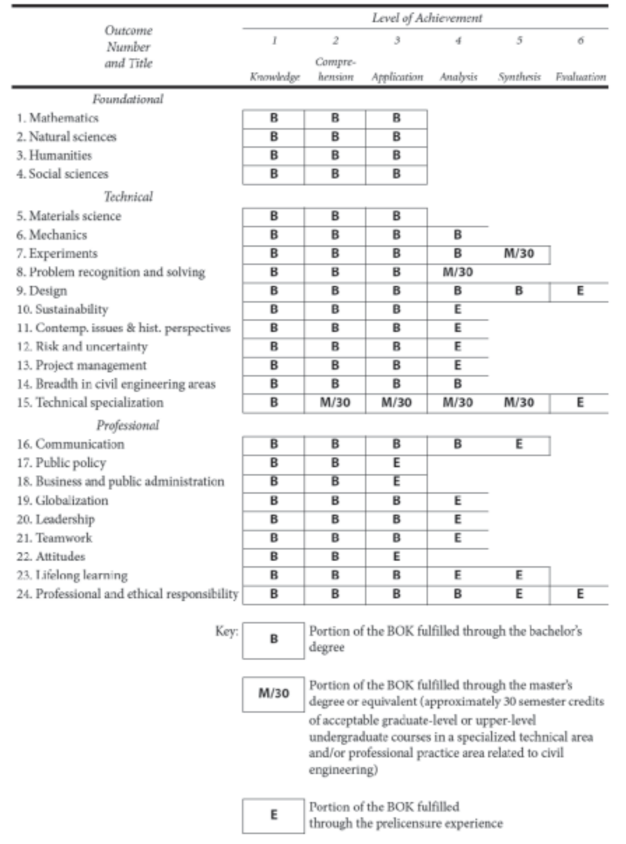
Professional: 16. Communication • 17. Public policy • 18. Business and public administration • 19. Globalization • 20. Leadership • 21. Teamwork • 22. Attitudes • 23. Lifelong learning • 24. Professional and ethical responsibility

The body of knowledge uses Bloom's Taxonomy to outline the necessary level of achievement for each of the 24 outcomes.

Implementation Status

The American Society of Civil Engineers has formed the BOK Educational Fulfillment Committee (BOKEdFC) to focus on the changes needed to engineering education. This committee is composed of representatives from universities with four-year civil engineering programs.

The National Council of Examiners for Engineering and Surveying considered the implementation of the BOK at their 2008 annual meeting and decided to establish a task force. The task force is provide an analysis of "(1) the potential educational, professional, regulatory, and economic impact of the master's or equivalent; and (2) any alternative solutions besides the master's or equivalent that could potentially address the challenge of better preparing engineering licensure candidates to enter the profession."



Outcome Number and Title	Level of Achievement					
	1 Knowledge	2 Comprehension	3 Application	4 Analysis	5 Synthesis	6 Evaluation
Foundational						
1. Mathematics	B	B	B			
2. Natural sciences	B	B	B			
3. Humanities	B	B	B			
4. Social sciences	B	B	B			
Technical						
5. Materials science	B	B	B			
6. Mechanics	B	B	B	B		
7. Experiments	B	B	B	B	M/30	
8. Problem recognition and solving	B	B	B	M/30		
9. Design	B	B	B	B	B	E
10. Sustainability	B	B	B	E		
11. Contemp. issues & hist. perspectives	B	B	B	E		
12. Risk and uncertainty	B	B	B	E		
13. Project management	B	B	B	E		
14. Breadth in civil engineering areas	B	B	B	B		
15. Technical specialization	B	M/30	M/30	M/30	M/30	E
Professional						
16. Communication	B	B	B	B	E	
17. Public policy	B	B	E			
18. Business and public administration	B	B	E			
19. Globalization	B	B	B	E		
20. Leadership	B	B	B	E		
21. Teamwork	B	B	B	E		
22. Attitudes	B	B	E			
23. Lifelong learning	B	B	B	E	E	
24. Professional and ethical responsibility	B	B	B	B	E	E

Key:
B — Portion of the BOK fulfilled through the bachelor's degree
M/30 — Portion of the BOK fulfilled through the master's degree or equivalent (approximately 30 semester credits of acceptable graduate-level or upper-level undergraduate courses in a specialized technical area and/or professional practice area related to civil engineering)
E — Portion of the BOK fulfilled through the prelicensure experience

Figure G-1. Entry into the practice of civil engineering at the professional level requires fulfilling 24 outcomes to the appropriate levels of achievement.

Curriculum

A curriculum committee of ASCE continues to work on specific issues associated with implementation of the *BOK*. An interesting figure (Figure G-1) taken from the *BOK* 2nd Edition summarizes the expected outcomes and the suggested academic settings in which these might be expected to be developed. These outcomes are apportioned between the BSE level and the MS or continuing education level, but are all expected of professional, licensed CE's in time. For more details about the curriculum committee and its extensive efforts, see: *http://www.asce.org/files/pdf/professional/curriculacommreportdec2006.pdf.* See also: *Wikipedia: http://en.wikipedia.org/wiki/Civil_Engineering_Body_of_Knowledge.*

The Body of Knowledge Committee of the Committee on Academic Prerequisites for Professional Practice (BOK Committee); American Society of Civil Engineers, *Civil Engineering Body of Knowledge for the 21st Century: Preparing the Civil Engineer for the Future*, second edition (Reston, VA: *American Society of Civil Engineers*, 2008), ISBN 978-0-7844-0965-7, *http://www.asce.org/professional/educ/bok2.cfm, retrieved 2008-06-09*.