A Report on the Workshop on the Future of Graduate Education in Materials

Tresa M. Pollock
Chair, Materials Department
University of California Santa Barbara

University Materials Council
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Acknowledgment: NSF International Center for Materials Research

Organizers
Tresa Pollock (UCSB)
Ram Seshadri (UCSB)
David Bahr (Purdue)
David Cahill (UIUC)
Kevin Hemker (JHU)
Richard Lesar (ISU)
Workshop Objective & Topics

Objective: Assess the current status of graduate education in materials, the driving forces for change and make recommendations for improving the graduate education experience.

- Perspective: historical origins of MS&E
- The current state of the graduate curriculum
  - Focus on the core curriculum
- Driving forces for change and the future curriculum
  - Theory, computation, data and integration
- The role of instrumentation and national user facilities
- Professional development of graduate students
- Building a safety culture
- Strategies for improving diversity
- The role of postdoctoral researchers
## Workshop Participants

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Workshop Program – Wednesday, June 10th

8:30 – 8:50 The Discipline of Materials: Historical Origins and Future Evolution (Kevin Hemker)
8:50 – 9:10 The External Driving Forces for Change in Graduate Materials Education (Al Romig)
9:10 – 9:55 Panel Discussion (Mary Galvin, Christine Ortiz, Kathy Faber)

10:20 – 10:40 The Core Graduate Curriculum (David Bahr)
10:40 – 11:00 Engaging the Broader Materials Community on Campus (Dave Cahill)
11:00– 11:45 Panel Discussion (Nicole Benedek, John Lewandowski, Dallas Trinkle)

1:00 – 1:20 Diversity in Materials (Liz Holm)
1:20 – 1:40 Curriculum Diversity and New Programs in Materials (Kathy Flores)
1:40 – 2:25 Panel Discussion (Eve Donnelly, Javier Garay, Britt Turkot)

2:50 – 3:10 Instrumentation and Graduate Education and Research (Ram Seshadri)
3:30 – 4:15 Panel Discussion (Justin Schwartz, Kurt Sickafus, Lincoln Lauhon)
4:15 – 4:45 – Wrapup
Workshop Program - Thursday June 11th

8:30 – 8:50 Needs for the Graduate Curriculum: Theory and Computation (Mark Asta)
8:50 – 9:10 Needs for the Graduate Curriculum: Data and Statistical Methods (Greg Rohrer)
9:10 – 9:55 Panel Discussion (Simon Philpot, Katsuyo Thornton, Tahir Cagan)

10:20 – 10:40 National Priorities and Graduate Education: MGI & ICME (Richard LeSar)
10:40 – 11:00 Entrepreneurship (James Rogers)
11:00– 11:45 Panel Discussion (Bruce Clemens, Paul Evans, Russell Holmes)

1:00 – 1:20 Building a Safety Culture (Sandeep Dhingra)
1:20 – 1:40 The Role of Postdoctoral Researchers (Russell Composto)
1:40 – 2:25 Panel Discussion (David Cahill, Terry Aselage, Dan Thoma)

2:50 – 3:10 International Experiences for Graduate Students (Tresa Pollock)
3:10 – 3:30 Industrial Internships and the Graduate Experience (Don Lipkin)
3:30 – 4:15 Panel Discussion – (Masao Takeyama, Tania Bhatia, Kathleen Stair)
4:15 – 4:45 – Wrapup
Workshop Program - Friday June 12\textsuperscript{th}

Capturing the Content

9:00 – 9:45 Define Broad Categories for a Report
9:45 – 10:30 Break into Subgroups

10:30 – 10:50 Coffee Break

10:50 – 12:00 Writing and Wrap-up

12:00 - Lunch
Historical Origins of MS&E

- New disciplines emerge via (a) splitting of old discipline or (b) integration of sub disciplines; Robert Cahn, *The Coming of Materials Science*
- Materials as a discipline emerged from an integration of Physical Chemistry, Chemical Physics and Metallurgy
- Materials Science was first incorporated into a department name in 1959 at Northwestern (Morey Fine; interviewed by phone)
- NSF and the MRLs / MRSEC had a strong influence on interdisciplinarity from the earliest days
- Industrial labs (Bell Labs, GE, Dupont, Dow) also had significant influence on the early development of the field and therefore the departments

“I have a very clear vision of what the future of Materials Science and Engineering will be like.”

- Morey Fine (June 2015)
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“I have a very clear vision of what the future of Materials Science and Engineering will be like.”
- Morey Fine (June 2015)

“It will be very different!”
Driving Forces for Change

- **Global Driving Forces:**
  - Global Instability, Resources (energy, water), Globalization, Demographics, Health, Climate, Availability of Capital

- **Education Forces:**
  - Growth in knowledge base
    - Breadth vs depth and curricula
    - University structure – colleges/departments
  - Virtual Presence; On-line learning

- **Research Customers**
  - DoD, NSF, DOE, NIH, NADA, USDA, FDA, DOT, Industry

- **The Role of the NAE**
  - Grand Challenges - modern day replacement for the grand challenge of space
  - Reports: 28 reports on Graduate Education in Engineering, 23 reports on Engineering Workforce Health; Reports on tools to design and manufacture materials
Graduate Education – The Core

• Prior snapshot NSF Workshop (2008)
  – “challenge is to define what constitutes a core knowledge base for materials”

• Surveyed the curriculum 20 schools; mix of public, private, stand alone, merged, programs vs department, ABET owning vs grad only
  – 16 / 20 schools have a core sequence (more than 8 years ago, more well-defined)
  – Average number of core courses is 4 (semester), ranged 1 – 6
  – The tetrahedron is still relevant!
  – (1) Thermo, (2) Kinetics or Diffusion or Phase Transformations, (3) Bonding /Structure / Defects, (4) Properties (wide variation; this may not be core at grad level) (5) Intro course, which is problematic
Driving Forces and the Future
Theory, Computation and Data

• The dramatic expansion in computational power is having a major impact on the entire spectrum of education and research
• There is pull from industry for development and implementation of computational tools and delivery of students who can use the tools
Computation in the Curriculum

- Introductory Overview Courses
  - Wide number of techniques, more projects than coding
  - Textbooks emerging (LeSar)
- Advanced Courses - algorithms and coding
- General consensus that computation and data topics should be integrated into curriculum
- Some specialized degree programs have been established
  - ICME M.S. Certificate Northwestern, Computational Materials Science emphasis, Illinois
- Alternative Delivery Modes having impact
  - Summer Schools, On-line resources (i.e, Nanohub )
- Uncertainty about the character of the future workforce needed by industry
Other “Beyond the Core” Considerations

• Data, big data and data analytics are of increasing importance
  – Materials in general has lots of small data
  – Synchrotrons, tomography, DFT are now bringing big data

• Graduate education should include simulation/numerical methods, statistical analysis, UQ, V&V, data analytics
  – Module development rather than entire courses would benefit entire community
  – Recommendation that the UMC and Professional societies collaboration on this topic
  – Build on emerging platforms (i.e. Dream 3D for 3D data)

• Integration of Computation and Data Tools with Experimental Techniques
  – Research in the multi-investigator environment is where this is being demonstrated, needs to work its way into curriculum
Graduate Education – Observations & Discussion

• We have a core strength and weakness: flexibility
• Is MSE interdisciplinary or a discipline that is part of interdisciplinary teams?
• Is the core really self-defining?
• Is the core still too crystalline centric?
• Do we need ABET-like objectives and outcomes at the graduate level?
• Where will new educational resources come from and how will they be organized?
• How do we unify the discipline to one voice?
  • A decadal study recommended
Instrumentation

• The role of instrumentation in Materials Research is changing
• An important role for shared experimental facilities, and their role in education
  • Need Ph.D. level staff to train and maintain; some local instrumentation essential for education
  • NSF Instrumentation Networks, MIPs
  • National User Facilities
• Modes of operation: Contractual, user, expert ...
• Maintaining state of the art instrumentation is increasingly challenging
  • Shrinking federal resources, rising acquisition costs
  • MRSECs
• Courses associated with techniques/instrumentation
• Development of new instruments still needs to be supported

Anatomy of a publication:
- Preparation (Crystalox MCG55)
- XRD (Philips X’Pert, APS-11-BM)
- Optical Microscopy
- SEM (FEI XL30)
- TEM (Tecnai G2)
- DTA (Setaram SETSYS)
- Thermal diffusivity (Antler Flashline)
- Thermopower etc. (Ulvac ZEM-3)
- DFT Calculations (VASP on a cluster)

The Materials Research Facilities Network (MRFN) now coordinates facilities at 27 different centers
National User Facilities

• Scientific User Facilities (SUFs) are operated by several of the federal agencies:
  – DOE, NSF, NIST

• From the Materials Science viewpoint, the facilities span capabilities for synthesis, characterization and computation; general User Proposals usually required.
Data Management

- Argonne developing capabilities using Globus on-line to handle large data sets from SUFs and address data management plans

- “Fire-and-forget” transfers
  - Optimize transfer
  - Automatic fault recovery
  - Automatic retry
  - Seamless security integration
  - 128-bit checksums

- Intuitive Web User Interface and powerful APIs for automation and integration
  - REST and Python APIs

- For more information contact Ben Blaiszik (blaiszik@uchicago.edu)
Professional Development of Grad Students

• The student – advisor relationship is core, but there should be much more to the graduate experience
• The graduate education experience should not be reproducing copies of the faculty
• Greater engagement of alumni and advisory boards
• The thesis committee should also serve as a mentoring committee
• Entrepreneurship as a career path should be supported
• Empower students on their own professional development
  – Industry Internships, organizing seminars/workshops, outreach, teaching, professional society involvement, international experiences
  – The graduate handbook is underutilized – make recommendations for their time investment in this
Graduate Internships...Why?

For Intern
• Engineering breadth, interpersonal breadth
• PhD MatSci ex-academia
• Paid 3-month interview, no tie required
• Build professional network

For Professor
• Build industry collaboration
• Student placement

For Industry Supervisor
• Focused work by fresh, dedicated talent
• Network with advisor, department
• 3-month interview
Diversity - Faculty Demographics

US Population

- Hispanic Male: 8.6%
- Hispanic Female: 8.3%
- Black/Af Am Male: 5.9%
- Black/Af Am Female: 6.4%
- Asian Male: 2.4%
- Asian Female: 2.6%
- Other Female: 1.5%
- Other Male: 1.4%
- White Male: 31.0%
- White Female: 32.0%

MSE Faculty

- Hispanic Male: 2%
- Hispanic Female: 1%
- Black/Af Am Male: 1%
- Black/Af Am Female: 0%
- Other Female: 3%
- Other Male: 3%
- White Female: 9%
- Asian Male: 20%
- Asian Female: 3%
- White Male: 59%

Compiled by Mary Galvin and Tristan Deppe, NSF.
Source: Resident population of the United States, by sex, race or ethnicity, and age: 2012: www.nsf.gov/statistics/wmpd/ and from American Society for Engineering Education
Diversity - The Pipeline

Women in MSE

Compiled by Mary Galvin and Tristan Deppe, NSF.
Source: American Society for Engineering Education
URM Faculty 2003 - 2013

MSE Faculty – all levels

Compiled by Mary Galvin and Tristan Deppe, NSF.
Source: American Society for Engineering Education
Enhancing Diversity

- Diversity – make sure the “why” is understood
- Formal training for faculty and students
  - Workplace culture: communication styles, team dynamics, effective response strategies
  - Organizational skills: time management, self-advocacy, negotiation
- Faculty Recruiting – Open searches
- Provide mentors, role models, and advocates
  - Formalize programs, fill gaps
  - Significantly correlated with retention and success
- Build safe-haven communities
  - Industry calls these Employee Resource Groups
  - Significantly correlated with retention and success

What is a Safety Culture?

• According to OSHA, “Safety cultures consist of shared beliefs, practices, and attitudes that exist at an establishment. Culture is the atmosphere created by those beliefs, attitudes, etc., which shape our behavior.”

• Safety culture is the ways in which safety is managed in the workplace, and often reflects "the attitudes, beliefs, perceptions and values that employees share in relation to safety".

• A set of core values and behaviors that emphasize safety as an overriding priority. While values are the foundation, safety culture is ultimately expressed through what is said and done—through behavior. In other words, "the way we do safety around here".

Dow-University Lab Safety Pilots (2012)

• Established interdepartmental teams (ChE, Chem, MSE) at U Minn, PSU and UCSB

• Delegations* (12-22 people) visited Dow to observe, train and learn

• Adapting and implementing best practices across departments

http://safety.dow.com
Recommendations for a good safety culture

- Need a safety professional who is an enabler not a policeman
- Need a system of work control documents and procedures
  - SOPs
  - Planning document for new activities
  - Record of training
- Establish internal safety-reporting protocols
- Incentivize graduate students and postdocs to report near misses (Starbucks cards?)
- Reward for identifying safety hazards and suggesting solutions
- Student safety committee and safety awards
  - Publicize this across the university
  - Student-generated safety tips
- Provide PPE to all students
  - Provide lockers for spare clothes to ensure correct dress-code
  - Appropriate storage and laundering for labcoats and PPE.
- Establish a UMC safety group
Post-doctoral Researchers

2014 Materials Science and Engineering Survey (University Materials Council & MRS)

Individual MSE Programs (State and Private)

- Are the number of post docs large enough to warrant a school wide mentoring program or is ad hoc mentoring sufficient?
- NIH has long required a post-doctoral mentoring plan
- Now NSF....

(NSF) Postdoctoral Mentoring Plan

1. Academic Integrity
   - Academic integrity ranges encompasses a broad set of responsibilities Responsible Conduct of Research (next page).

2. Career Counseling

3. Publications and Presentations

4. Teaching and Mentoring Skills

5. International Research and Industry Research Visits
   - Particularly if these opportunities were not available during Ph.D.

6. Biannual reviews.
NIH Post-doctoral Mentoring
Responsible Conduct of Research (RCR) at University of Pennsylvania
covers the following topics

1. Data acquisition, management, sharing, and ownership
2. Materials, their ownership, and material transfer agreements
3. Intellectual property, copyrights, patents, licenses, and technology transfer
4. Authorship and publication practices
5. Peer review
6. Mentor/trainee responsibilities, and collaborative science
7. Human subjects
8. Research involving animals
9. Environmental safety: radiation, chemicals, and microbial agents
10. Research misconduct
11. Conflict of interest
12. Preparing grant proposals
13. Research administration: financial and personnel management

** Each rubric includes University policies, lectures, guidelines, interactive quizzes, Federal policies, and hyperlinks to websites at other institutions.
Summary

• MSE does have a core but still suffers from lack of complete integration

• Computation, theory and data will have a significant impact on the field

• The graduate students of tomorrow should and probably will look much different than us

• Pressing issues include instrumentation, safety, diversity and professional development of graduate students and postdocs

• A report is being written – where should it be published? Additional topics?