Preparing the Future Workforce for Careers in Science and Engineering

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XSEDE
Extreme Science and Engineering Discovery Environment
The Need for a Modeling Savvy Workforce

- Documenting the Need
- How science and engineering (and social science and humanities) research is done
- What should our students know?
- Implementing changes to the curriculum
- Resources and services to assist in making changes
Crucial Tools for Manufacturing

• At Ford, HPC ...allows us to build an environment that continuously improves the product development process, speeds up time-to-market and lowers costs.

• The ongoing use of modeling and simulation resulted in new packaging and product design that propelled the brand to a leading market position over a several-year period.
Large Scale Video Analytics

- Creation of human-machine hybrid process to analyze and archive video images
- Allow exploration of cultural trends through analysis of video archives
Analysis Process

Source: http://www.academia.edu/2653762/Large_Scale_Video_Analytics_On-demand_iterative_inquiry_for_moving_image_research
A diagram illustrating the relationship between realism and tractability of various economic models. The models are categorized along two dimensions: realism and tractability. The ideal model is positioned at the top-right corner. Models include:

- **Multi-agent model**: Lux & Marchesi '99
- **Giardina & Bouchaud '03**: SFI stock market
- **Arthur, Holland, LeBaron, Palmer, & Taylor '97**: Prototype of stock market
- **Caldarelli, Marsili & Zhang '97**: 1st ABM
- **Kim & Markowitz '89**: El farol bar
- **Arthur '94**: Minority Game
- **Challet & Zheng '97**: Cavagna '99
- **Challet, Marsili & Zecchina '00**: Analytical solution
- **Delli Gatti, Gallegati, Greenwald, Russo & Stiglitz '08**: Credit network
- **Levy & Solomon '95**: Leverage effect
- **Thurner, Farmer & Gijnakoplos '09**: Percolation
- **Cont & Bouchaud '00**: Brock & Hommes '97

The diagram is adapted from a picture by M. Marsili.
Making Progress in Science

• A number of studies document the need for computational scientists
  – "... computer modeling and simulation are the key elements for achieving progress in engineering and science.” NSF Blue Ribbon Panel on Simulation-Based Engineering Science
  – “Unfortunately, the translation of systems biology into a broader approach is complicated by the innumeracy of many biologists” Cassman et al. Barriers to Progress in Systems Biology, Nature Vol. 438|22/29 December 2005
  – Nearly 100% of the respondents indicated that HPC tools are indispensable, stating that they would not exist as a viable business without them or that they simply could not compete effectively. IDC Study for Council on Competitiveness of Chief Technology Officers of 33 Major Industrial Firms
Computation is how science is done
Marketing Computational Science
Computation is Central to How Science is Done

- Computation lets us explore phenomena that are too big or complex to experiment, too small, or changes too fast or too slowly.
- Computation allows us to explore more options more quickly.
How we teach is just as important as what we teach

Seymour and Hewitt: Talking About Leaving

Students switching to non-science majors
Over 90% indicated poor instruction among reasons for switching
26% had trouble learning the basic concepts
How Do We Go From the Abstract to the Applied?

\[ F = -kx \]

\[ W_c = -\Delta U \]

\[ U = \frac{1}{2} kx^2 \]

\[ E = K + U \]

\[ m \frac{dv}{dt} = F_{\text{net}} \]

\[ x(t) = x_0 + v_0 t + \frac{1}{2} \left( \frac{F_c}{m} \right) t^2 \]
Challenges to Changing How and What We Teach

• We tend to teach in the way we were taught
• Computational science is interdisciplinary
  – Faculty workloads fixed on disciplinary responsibilities
  – Coordination across departments is superficial
  – Expertise at universities is spotty
• Major time commitments are required to negotiate new programs and develop materials
• Curriculum requirements for related fields leave little room for new electives
• Change is hard
Pathways to Reform

• Integrate computational examples into basic science and math courses
• Create general education courses that introduce simulation and modeling concepts and applications
• Combine those efforts to create formal concentrations, minors, or certificates in computational science
• XSEDE is working with institutions to assist with those activities
What Do Students Need to Know?

• Considerable discussion across many disciplines
  – Difficulty working from general conceptual ideas to specific skills and knowledge
  – Need to bridge disciplinary boundaries and terminology

• Using a competency based model to arrive at consensus of the essential knowledge base

• Competencies reviewed by both academic and non-academic experts

• See http://hpcuniversity.org/educators/competencies/
Ohio Minor Program Example

- Undergraduate minor program
  - 6-8 courses
  - Varies based on major
- Faculty defined competencies for all students
- Reviewed by business advisory committee
- Program started in Autumn 2007
- Agreements to share students at distance, instructional modules, revenues, and teaching responsibilities

### Competencies for Undergraduate Minor

<table>
<thead>
<tr>
<th>Competency</th>
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<tbody>
<tr>
<td>Simulation and Modeling</td>
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<tr>
<td>Programming and Algorithms</td>
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<tr>
<td>Differential Equations and Discrete Dynamical Systems</td>
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<td>Numerical Methods</td>
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<td>Optimization</td>
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<tr>
<td>Parallel Programming</td>
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<tr>
<td>Scientific Visualization</td>
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<tr>
<td>One discipline specific course</td>
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<tr>
<td>Capstone Research/Internship Experience</td>
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<tr>
<td>Discipline Oriented Courses</td>
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Example Competencies Simulation and Modeling

• Explain the role of modeling in science and engineering
• Analyze modeling and simulation in computational science
• Create a conceptual model
• Examine various mathematical representations of functions
• Analyze issues in accuracy and precision
• Understand discrete and difference-based computer models
• Demonstrate computational programming utilizing a higher level language or modeling tool (e.g. Maple, MATLAB, Mathematica, Python, other)
• Assess computational models
• Build event-based models
• Complete a team-based, real-world model project
• Demonstrate technical communication skills
Detailed Descriptors

**Explain the role of modeling in science and engineering**

**Descriptors:**
- Discuss the importance of modeling to science and engineering
- Discuss the history and need for modeling
- Discuss the cost effectiveness of modeling
- Discuss the time-effectiveness of modeling (e.g. the ability to predict the weather)
- Define the terms associated with modeling to science and engineering
- List questions that would check/validate model results
- Describe future trends and issues in science and engineering
- Identify specific industry related examples of modeling in engineering (e.g., Battelle; P&G, material science, manufacturing, bioscience, etc.)
- Discuss application across various industries (e.g., economics, health, etc.)
Flexibility in Implementation

• Adapt existing courses by adding computationally oriented modules
• Discipline oriented courses dependent on existing faculty expertise and interests
• Different subsets of required and optional competencies tied to major, required math, and example projects
Graduate Level Competencies

• Assumes some of the background of an undergraduate
• Focus more on research skills
• Core areas focus on the computer science and related modeling skills
• Need to branch into a wider array of specializations based on the nature of the graduate program
Graduate Competencies

Specializations
- Discipline-Specific HPC Simulation

HPC Application Development
- High Performance Scientific Computing

Data Intensive Computing
- Intermediate Scientific Computing

Core Area 1
- Physical Sciences and Engineering

Core Area 2
- Computer Science

Subject Areas
- Life Sciences and Bioinformatics
XSEDE Vision

The eXtreme Science and Engineering Discovery Environment (XSEDE):

enhances the productivity of scientists and engineers by providing them with new and innovative capabilities

and thus

XSEDE accelerates open scientific discovery by enhancing the productivity of researchers, engineers, and scholars and making advanced digital resources easier to use.
XSEDE Education Mission

• To prepare a diverse community of the current and next generation of researchers, scholars, educators, and practitioners in the use of data analysis and management, modeling, simulation, and visualization techniques.
Assistance with Program Development

- Campus visits
- Model programs and competencies to shorten the time to implementation
- Assistance with program proposals
Developing Faculty Expertise

• Faculty professional development workshops
  – Two to six day workshops on a variety of topics
    • Computational thinking
    • Computational science education in science and engineering domains
  – Focus on local/regional audiences to reduce travel costs
  – Subsidies for faculty to travel to workshops at other sites
Special Workshops for Faculty and Students

- Development of synchronous and asynchronous education and training sessions
  - Multi-site broadcasts of workshops
  - Online training and education modules
  - Experimenting with full courses that can be widely shared for credit and non-credit inclusion in curricula (e.g. https://www.xsede.org/xsede-offers-free-online-parallel-computing-course)
Repository of Shared Materials

- Developing a repository of computational science education materials
  - Reviewed by professional staff and faculty
  - Indexed by subject and a detailed competency-based ontology
  - Goal: trusted, comprehensive source of information for computational science educators
  - http://hpcuniversity.org/resources/search/
Some Other Opportunities

- Journal of Computational Science Education
  - www.jocse.org
  - Peer reviewed articles on computational science education experiences
- Become a reviewer or contributor to the online repository
- Use the XSEDE online training materials
  - www.xsede.org
A Push for Positive Change

• We must change how and what we teach to adequately prepare our students for the workforce
• Change need not be revolutionary
• Review your curriculum to target the appropriate changes
• Ask for XSEDE assistance
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