Enhancing Engineering Education Through Technical Computing and Model-Based Design

Jim.Ryan@MathWorks.com
## Key Ideas for Today

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<tr>
<th>Challenges in Engineering Education</th>
<th>Ideas to Help Overcome Challenges</th>
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<tr>
<td>Students need to obtain broader and deeper skill sets</td>
<td>Integrated multi-disciplinary curriculum; team-based learning</td>
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<td>→ to solve “grand challenges” worldwide</td>
<td>→ through a common set of tools for technical computing</td>
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<td>Students need to learn real-world, systems engineering</td>
<td>Interactive exploration; accelerated innovation, hands-on</td>
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<td>→ to hit the ground running after graduation</td>
<td>→ through Model-Based Design</td>
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  • **Collaboration**  
  → through a common set of tools for **technical computing** |
| → to solve “grand challenges” worldwide | |
| Students need to learn “real-world, systems engineering” | • **Interactivity**  
  • **Project-Based Learning**  
  → through **Model-Based Design** |
| → to hit-the-ground-running after graduation | |
2010 White House Report on “Simulation-Based Engineering and Science for Discovery and Innovation”

“…use of (Simulation-Based Engineering and Science) SBE&S by U.S. manufacturers is critical to creating and keeping good, high-paying jobs…and in addressing critical 21st century problems facing the U.S. and the world.”

“This viewpoint has led the Council on Competitiveness to state that computational modeling and simulation ‘is not only a key tool to increasing competitiveness, it is also a tool that is essential to business survival.’”

Simulation is essential for companies to remain competitive

“…use of SBE&S is not exploited as routinely as it should in industrial product design and innovation”

“Necessary expertise is often difficult to find”

Companies need more people with simulation skills

National Science and Technology Council  http://www.whitehouse.gov/sites/default/files/microsites/ostp/FTAC_MS%20Report.pdf
<table>
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<tr>
<th>Job Title</th>
<th>Location</th>
<th>Posting Date</th>
<th>Requisition ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chassis Brake Controls System Engineer</td>
<td>US-MI Warren</td>
<td>Feb 15, 2011</td>
<td>ENG0010543</td>
</tr>
<tr>
<td>Electric Drive Controls - Sr Project Engineer</td>
<td>US-CA Torrance</td>
<td>Feb 10, 2011</td>
<td>ENG0009655</td>
</tr>
<tr>
<td>Chassis Controls Simulation Engineer</td>
<td>US-MI Milford</td>
<td>Feb 15, 2011</td>
<td>ENG0010196</td>
</tr>
<tr>
<td>PWT Hybrid and Electric Architecture Analyst</td>
<td>US-MI Pontiac</td>
<td>Jan 27, 2011</td>
<td>ENG0010024</td>
</tr>
<tr>
<td>Sr Systems Engineer - High Voltage Systems Integration &amp; Analysis</td>
<td>US-MI Milford</td>
<td>Feb 8, 2011</td>
<td>ENG0010136</td>
</tr>
<tr>
<td>Battery Algorithm Engineer</td>
<td>US-MI Warren</td>
<td>Jan 31, 2011</td>
<td>ENG0010358</td>
</tr>
<tr>
<td>PWT Transmission Algorithm Development Engineer</td>
<td>US-MI Milford</td>
<td>Feb 11, 2011</td>
<td>ENG0010420</td>
</tr>
<tr>
<td>Sr Project Engineer - HIL and Advanced Development</td>
<td>US-MI Warren</td>
<td>Jan 24, 2011</td>
<td>ENG0010265</td>
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The Chevy Volt: Innovation Realized

- More systems engineering
- More integration of cross-disciplinary technologies
- More global team engineering
- More simulation + “software inside”

“Automatic code generation accounted for nearly 100% of the Volt’s powertrain software.”

-- SAE Automotive Engineering International online
1-Nov-2010  http://www.sae.org/mags/aei/9027
Globally Distributed Engineering

Simulation-based engineering facilitates collaboration and accelerates innovation

Old (Physical) Approach
- Expensive
- Slow
- High Risk

New (Virtual) Approach
- Cost-Efficient
- Faster; electronic
- Reduced Risk
Integrated Curriculum and Collaboration

→ through a common set of tools for Technical Computing
### Key Ideas for Today: 1 of 2

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- **Project-Based Learning**  
→ through **Model-Based Design** |
## University Feedback on Curriculum

### Problems:
- Frustrated students
- Frustrated instructors
- Time inefficiencies in curriculum

### Current Approach

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<td>Students are taught how to use different software in entry-level <em>Math</em> or <em>Programming</em> courses, but expected to use MATLAB in higher-level <em>Engineering</em> courses.</td>
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### University Feedback on Curriculum (cont.)

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<th>Current Approach</th>
<th>Alternative Approach</th>
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<td>Students taking certain courses are expected to know MATLAB, but were never taught it.</td>
<td>Students learn MATLAB in entry-level “Engineering Gateway” courses</td>
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<td>Students are taught how to use different software in Math or Programming courses, but expected to use MATLAB in higher-level Engineering courses.</td>
<td>Students are taught entry-level Math and Programming courses with MATLAB</td>
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<td>Students are taught MATLAB their freshman year, but they don’t encounter again until much later in curriculum.</td>
<td>Students use MATLAB in 1 or more core courses each year (especially 2nd year); coordinate</td>
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Goal
Help 1st-year engineering students learn programming concepts and reusable skills

Approach
Decided to teach *Introduction to Engineering Computation* with MATLAB instead of C++

Outcomes
- Integrated curriculum; accelerated learning
- Enduring collaboration enabled
- Customers satisfied

“In open meetings with sophomores and juniors who took the MATLAB-based course as freshmen, we heard over and over how pleased they were to have learned MATLAB in their first year.

I’ve heard nothing but positive remarks about the course from the engineering faculty as well.”

Prof. Stormy Attaway

Integrated, Multi-Disciplinary Curriculum

1. Graduate-level Dynamics
2. Controls Programming
3. Year 4 Electrical
4. Year 3 Controls
5. Year 2 Programming
6. Year 1 Graduate-level Dynamics
7. MATLAB course
8. Electrical
Integrated, Multi-Disciplinary Curriculum

- Year 1
  - MATLAB course

- Year 2
  - Programming

- Year 3
  - Controls

- Year 4
  - Dynamics
  - Graduate-level

Electrical
Integrated, Multi-Disciplinary Curriculum

- **Electrical**
  - Year 1: MATLAB course
  - Year 2: Programming
  - Year 3: Dynamics
  - Year 4: Controls

- **Mechanical**
  - Year 1: MATLAB course
  - Year 2: Programming
  - Year 3: Controls
  - Year 4: Dynamics

- **Aerospace**
  - Year 1: MATLAB course
  - Year 2: Controls
  - Year 3: Programming
  - Year 4: Dynamics

- **Bio(medical)**
  - Year 1: MATLAB course
  - Year 2: Controls
  - Year 3: Programming
  - Year 4: Dynamics
Integrated, Multi-Disciplinary Curriculum

Year 1
- Year 1
- Year 1
- Year 1
  - Electrical: Graduate-level Dynamics, Controls
  - Mechanical: Graduate-level Controls, Programming
  - Aerospace: Graduate-level Programming, Dynamics, Controls
  - Bio(medical): Graduate-level Programming

Year 2
- Year 2
- Year 2
- Year 2
  - Electrical: Controls, Programming
  - Mechanical: Programming, Dynamics
  - Aerospace: Programming, Dynamics
  - Bio(medical): Programming

Year 3
- Year 3
- Year 3
- Year 3
  - Electrical: Controls, Programming
  - Mechanical: Programming, Dynamics
  - Aerospace: Programming, Dynamics
  - Bio(medical): Programming

Year 4
- Year 4
- Year 4
- Year 4
  - Electrical: Graduate-level Dynamics, Controls
  - Mechanical: Graduate-level Controls, Programming
  - Aerospace: Graduate-level Programming, Dynamics, Controls
  - Bio(medical): Graduate-level Programming

Engineering Fundamentals with MATLAB course
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**• Collaboration**  
→ through a common set of tools for **technical computing** |
| Students need to learn “real-world, systems engineering” → to hit-the-ground-running after graduation | **• Interactivity**  
**• Project-Based Learning**  
→ through **Model-Based Design** |
Interactivity and Project-Based Learning

→ through Model-Based Design
### Key Ideas for Today: 2 of 2

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Students need to learn “real-world, systems engineering” → to hit-the-ground-running after graduation

• Interactivity  
• Project-Based Learning  
→ through Model-Based Design
Accelerating Innovation, Virtually

- Build Model
- Simulate
- Modify Model
- Accept Design

- Explore more What-if scenarios
- More affordable hands-on learning
- Accelerate via Optimization; Monte Carlo; Parallel Computing
- Higher confidence built in; same software model controls the hardware
- Unified, multi-domain modeling platform decreases translation errors
University of Stuttgart

Goal
Excite students in Automatic Controls course; help them connect theory to real-world engineering

Approach
Customized MATLAB and Simulink to create SpacecraftRT, an educational game

Outcomes
- Hands-on interactivity rapidly engages students; provides context for theory
- Provides easy link between using GUI for What-if exploration followed by learning MATLAB and Simulink

“Games allow students to apply complex methods to realistic, yet simple, control problems. It is a small step from GUI-based controller design to MATLAB coding.”

Prof. Frank Allgöwer
Institute for Systems Theory and Automatic Control

Problems in Traditional Development Process

**Paper Requirements and Specifications**
- Difficult to manage

**Manual Coding**
- Slow; error-prone; not portable across targets; not repeatable

**Physical Prototyping and Testing**
- Slow, expensive, and incomplete; system integration issues found late; poor traceability
Advantages of Model-Based Design

Executable Specification
Unambiguous; One set of models for all teams; Model whole system including environment
Advantages of Model-Based Design

Executable Specification
Unambiguous; One set of models for all teams; Model whole system including environment

Automatic Code Gen
Faster; more reliable & repeatable; portable across hardware targets
Advantages of Model-Based Design

- **Executable Specification**: Unambiguous; one set of models for all teams; model whole system including environment.

- **Automatic Code Gen**: Faster; more reliable & repeatable; portable across hardware targets.

- **Continuous Test and Verification**: Less physical prototyping; broader design exploration; errors detected earlier; greater confidence in design; re-use.
Model-Based Design at Purdue University

Goal
Develop a Power Electronics Lab to provide the students hands-on experience in the design of digitally-controlled power electronic circuits.

Approach
Adopted Simulink and SimPowerSystems for design and control of power electronics. Real-Time Workshop enables students to quickly prototype control strategies via code-generation.

Outcomes
- Project-based learning through Model-Based Design
- Students obtaining greater context for theory
- Students prepared for jobs in energy & power

"Simulink establishes a bridge between digital signal processing, digital control, and power electronics..."

"...by providing a unified environment for design, rapid prototyping, and testing of student designs with reduced development time."

Prof. Maryam Saeedifard
Assistant Professor of Electrical and Computer Engineering
EcoCAR Student Competition

**Goal**
Minimize fuel consumption, reduce emissions, retaining appeal (by U.S. Department of Energy)

**Approach**
16 student-teams using Model-Based Design to develop and integrate advanced technology into a “more green vehicle”

**Outcomes**
Hands-on, real-world type innovation with new, clean-vehicle technologies

http://www.green-garage.org/
Innovation at ET-Robocon

TOKYO
Regional Competition

1st place in Speed portion

“This team was in a different world.”

“I see Simulink models at work, but didn’t realize the real power of the software.”
In Summary...
## Key Ideas

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• Project-Based Learning  
→ through Model-Based Design |
Since this ECEDHA conference is focusing on “Power & Energy”...
MathWorks Industrial Applications

- Automotive
- Biotech & Pharmaceutical
- Energy Production
- Industrial Automation & Machinery
- Communications
- Electronics & Semiconductors
- Aerospace & Defense
- Financial Services
- Biotech & Pharmaceutical
Customer Successes in Energy

GAS NATURAL FENOSA (Spain)
- Predict energy supply and demand

Horizon Wind Energy (USA)
- Develop revenue forecasting and risk analysis tools

Hydro-Québec (Canada)
- Model Wind Power Plant Performance

ABB (Sweden)
- Develop software for Power Electronic Controller

Alstom (Czech Republic)
- Safety-Critical Power Converter Control Systems
Enhancing Engineering Education through Technical Computing and Model-Based Design

Jim.Ryan@MathWorks.com
Wind Turbine Model

[Wind turbine model diagram with data graphs]

Pitch Command and Angle (deg)

Wind

Yaw Actuator Torque

[Graphs showing pitch command, wind speed, and yaw actuator torque over time]

S1, S2, S3 (function blocks in diagram)
Multi-Domain Choice; Unified Platform

Graphical; Block Diagram

Physical Modeling

Symbolic Computation

Numeric Computation
MATLAB in Academia

5000+ universities worldwide use MATLAB

- Includes all of the Top 200 World Universities*

1 million+ students and faculty have campus-wide access to MathWorks tools through TAH licenses

- TAHs in place at more than 225 academic institutions, including 13 of the Top 20 World Universities*

* Source: Times Higher Education-QS World University Rankings 2010
Support for Academia

Downloadable Classroom Resources

Over 1,200 MATLAB and Simulink Based Books
...in 27 Languages

Academic License Options

Student Competition Sponsors

For campuses, professors, & students
Model-Based Design in Education

Innovation and systems perspective throughout engineering education

- Enables teaching with hands-on models
- Enables project-based learning
- Encourages innovation through exploration of alternative design concepts
- Drives more mathematics into design of systems
- Eliminates low-level C/C++/HDL coding
- Promotes collaboration across multiple disciplines
Rose-Hulman: Model-Based Systems Design??

- [http://ece-1.rose-hulman.edu/herniter/](http://ece-1.rose-hulman.edu/herniter/)
U Michigan: Teaching Embedded Control Systems

<Add details condensed from story>
Penn State GATE* Program

Use of MathWorks software

- Goal: Teach students about modern automotive product development processes
- Students designed new hybrid-electric engine that improved fuel efficiency from 45 to 119 miles per gallon.

Benefits

- Students able to hit-the-ground-running when taking jobs in industry

“I was recruited to work at General Motors before I even finished graduate school.
And I think that one of the things that made me attractive was my hands-on experience with tools like MATLAB and Simulink…”

Melanie Fox, PhD Candidate
GM Engineer

“One of the reasons we chose MathWorks products to standardize our course on was because we see that’s actually what industry is using.”

Joel Anstrom, PhD
Director, GATE Program

*GATE = Graduate Automotive Technology Education
We wanted to standardize on one platform for the course, and we didn’t want to have to teach that as well. With MathWorks tools, our students can do both modeling and analysis, and then develop an embedded controller without switching software platforms. That is invaluable.”

Dr. Joel Anstrom, Penn State University

**Challenge**
To teach engineering graduate students advanced vehicle powertrain technologies using hardware-in-the-loop methodologies

**Solution**
Use MathWorks tools to set up an interconnected campus-wide HIL network and help students apply high-level concepts, visualize results, and control real hardware

**Results**
- Labs set up in minutes
- Career opportunities enhanced
- Research and teaching integrated
MATLAB beyond the classroom

More job postings require MATLAB skills than any other commercial mathematical computing tool

More Facebook fans than any other tech computing software
• 117,000+ and growing

19 million hits from search

46 million annual visitors to mathworks.com and 1.2 million monthly visitors to MATLAB Central

All statistics as of February 2011
"GM started modeling with Simulink, then graduated to Real-Time Workshop Embedded Coder to create the C code that went into the Volt's electronic control system."

"GM engineering teams said they employed model-based design and simulation in the prototyping of the Volt's propulsion and battery management systems, even as the technology was barely emerging from the research stage."

-- Design News: The Mechatronics Zone
5-Nov-2010
Enabling Collaborative Engineering, Globally
Enabling the Technical Learning Life-Cycle

- Pre-university
- University
- Career
  - Academia
  - Government
  - Industry
Avoiding the “2\textsuperscript{nd} Year Sag” Syndrome

1\textsuperscript{st} year  2\textsuperscript{nd} year  3\textsuperscript{rd} year  4\textsuperscript{th} year

Desired proficiency level
Avoiding the “2nd Year Sag” Syndrome

Desired proficiency level
Graduated use of automated computations

1. Students perform manual derivations & calculations to demonstrate mastery of core concepts
2. Students use calculators to check their work
3. After demonstrating mastery of core concepts (and proper use of their calculator), students are permitted to use calculators to automate their work

Benefits of this approach:
   a) Accelerate time-to-results
   b) Solve more difficult (realistic) engineering problems
   c) Improve the accuracy & reliability of computations

→ Methodical progression from White Box to Gray Box
Enabling the T-shaped Engineer

Combining deep subject knowledge...

...with broad multi-disciplinary awareness.
Feedback – 3/4/11

- Do not use acronym MBD
- Several slides have too many words – 22, etc.
- Why use Simulation-Based Engineering?
- Skirting the edge of “selling”, “advertising”. Be careful – look to pull back. Refer to “technical computing software” instead of “we”
- Did not quite get the internationalization part. Maybe we pull this concept from this talk. We are not particularly unique. Do You Speak MATLAB? ad slide didn’t work.
- Slide 3 – listing of jobs was not clear. Can you perhaps only use the Volt example and set it up better?
  – Do not highlight the Simulink connection. Say that you searched for simulation jobs and here is a sample.
  – Maybe show the entry level jobs instead?
- Slides on the integrated courses
  – Do not introduce freshmen course
  – Tweak the visual representation of MATLAB as a foundation
  – Needs some clean up
  – Start this whole section with what is broken. Then, get into the various ways this problem is solved - intro course / gateway course / frequent refreshing
- Slide 17 – your words did not match the words on the slide
- Slide 21 –
  – emphasize the multi-domain aspect
  – Use CHOICE or APPROACH as the concept rather than PROGRESSION and refer to A TECHNICAL COMPUTING platform
  – Maybe remove the product names and use general terms instead
- Slide 23 –
  – How do we define MBD? Could be done if slides were ordered better.
  – walls-dropping is this the best? Will this resonate with the specific audience?
  – Needs more slides or a new way to talk about it
- ET Robocon
  – “MathWorks staff”
- Change to: Challenge/Problem -> Approach -> Outcomes
- What happened to the Four I’s? They did not carry through.
Feedback – 3/4/11 from Rich

- Slide 2: too long; shorten and make more impactful; it’s not clear why it’s relevant to academia
- Slide 3: one engineer vs many engineers; give an example
- 7: not making the transition clear
- 14: need the why/Benefits. B.U. story helps → maybe foreshadow this
- 21: show Product Family Overview immediately before this slide?
- MBD not well defined
- 26: Define EcoCAR
Some “Healthier”, More Productive Patterns

1. Leverage 3rd-Party Teaching & Learning Resources
   - MathWorks video tutorials (~10 minutes per video, 120 min total)
     [www.mathworks.com/academia/matlabtutorial](http://www.mathworks.com/academia/matlabtutorial)
   - 1400+ books; many *Getting Started* type
   - MathWorks “Classroom Resources”; MATLAB Central, Answers

2. Unify Introductory Course(s) Freshman Year
   - Math courses include MATLAB assignments
   - *Introduction to Programming* course with MATLAB
   - Each Department ‘Gateway‘ course includes MATLAB
   - All 1st-year Engineers take same Gateway course with MATLAB

3. Reinforce Use Throughout Curriculum
   - Other courses in curriculum include MATLAB-based homework assignments
Notes

- Get edited by an editor on call

- Slide 5: focus on global engineer, not selling

- Slide 15: look at prior feedback around year 1 MATLAB use. Maybe focus on ECE perspective primarily from an earlier slide

- Slide 29: depends on learning objectives and instructor preferences

- Do you speak MATLAB doesn’t transition well; don’t need it?

- Patterns vs Alternative Approach: Emphasize this is what we’ve heard or people have told us
  - Students need to see more of what MATLAB can do (beyond just programming, for instance)

- Model-Based Design schematic: include something about using data from real-world data (beyond “just simulation”)
Traditional Development Process

- **Research**
- **Requirements**
- **Specifications**
- **Design and Implementation**
  - C/C++
  - Algorithm Design
  - MCAD/MCAE
  - EDA
  - Embedded Software
  - Embeddable Algorithms
  - Mechanical Components
  - Electrical Components

**Integration and Test**
Problems in Traditional Development

- **Requirement Documents**
  - Difficult to analyze
  - Difficult to manage as they change

- **Paper Specifications**
  - Easy to misinterpret
  - Difficult to integrate with design

- **Physical Prototypes**
  - Incomplete and expensive
  - Prevents rapid iteration
  - No system-level testing

- **Manual Coding**
  - Time consuming
  - Introduces defects and variance
  - No portability across targets

- **Traditional Testing**
  - Design and integration issues found late
  - Difficult to feed insights back into design process
  - Traceability
Advantages of Model-Based Design

- Environment Models
- Physical Components
- Algorithms

Executable Specification
- Unambiguous spec
- One set of models for all teams
- Model whole system including environment
- Early validation and test development
Advantages of Model-Based Design

Automatic Code Generation
- Eliminate unnecessary manual coding
- Eliminate hand-coding errors
- Hardware target portability
- Improved testability due to repeatability
- Bridge between domain, software and hardware knowledge
Advantages of Model-Based Design

Continuous Test and Verification
- Detect errors early in development
- Reduce dependency on physical prototypes
- Implementations that work the first time
- Reuse test suites across development stages
Model-Based Design in Industry

Dramatically improves how systems are designed, implemented, and tested

- **Increase** math and algorithmic content of system design
- **Drive** innovation through early design iterations
- **Eliminate** manual coding
- **Improve** quality through early verification and validation
- **Allow** collaboration across disciplines
- **Cause** collaboration across development stages
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Multi-Domain Choice; Unified Platform