Concept Inventories:
– a foundation for an E³ education –

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So what is an $E^3$ education?

*Ethical*
*Effective*
*Efficient*

An education designed to equip the next generation of engineers to tackle the deep technical challenges and ethical choices of a world under unprecedented stress.
Recent engineering headlines:

• Inadequate levees breached due to Katrina
• Engineers fail to convince management of risk of Columbia’s return to earth*
• Planned obsolescence of cell phones, computers…
• Global warming heating up while we build more bigger, heavier CO$_2$-emitting cars
• Unhealthy air and water, inside and out

And many more, here and abroad…

Are these engineering problems engineering education problems?

• YES!

“Engineers...shall hold paramount the safety, health and welfare of the public...and conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession.”

NSPE Code of Ethics [1]
How can we equip our students to handle *tough* engineering questions?

- Can our teaching of engineering fundamentals be more effective?
- Can we shut the book on open book tests?
- Can we teach in a way that our students will not just calculate answers…
- But develop fluency in the conceptual foundations we professors often take for granted?
How can we equip our students to handle the *ethical* questions?

- Can we reduce their fear and increase their comfort with confronting complex unknowns?
- Can we teach them that being wrong is not failure but an opportunity for deeper inquiry, discussion and better learning?
- Can our teaching model the process of engaged inquiry?

Wyatt (2005) [3]
How can we equip our students to handle the *unknown*?

- Can we make time for teamwork, written and oral communication, multi-disciplinary inquiry?
- Can we develop curricula that leaves space for individual explorations of self and the problems to come?
- Can our teaching of engineering fundamentals be more *ethical*, *effective*, and *efficient*?
Elements of an E³ engineering education:

• A curriculum of fundamentals structured from distilled, collective wisdom —
• Taught in a manner that inspires and engages the minds of all types of students for the tough tasks ahead.
• Develops conceptual fluency and thoroughness.
• Identifies and reshapes individual misconceptions.
• Teaches teamwork, creativity, even patience
• Integrates social values, societal consequences, and an awareness of the impact of our choices on the world.
A fantasy?
Can an E³ *engineering* education really do all that?

Probably not.

But if we can leave some time –

- Unpack our jammed curricular requirements.
- Identify *and teach* what really matters: both technically and in the professional skills.
- Allow them time to process, ask questions, be creative, even…
  - take upper level courses in other disciplines –

  *…it is possible.*
Major elements of a comprehensive strategy:

• Identify and distill core technical competencies, ideally with a team of peers.
• Interview students & extract common misconceptions.
• Develop and share adaptable teaching approaches and tools that can be PROVEN.
• Improve curriculum relevance (professional skills, too) and efficiency, then reduce overall prescribed hours!
• Encourage and integrate non-engineering course work.
Element One:

Concept Inventories

– a foundation for an $E^3$ education –
What is a Concept Inventory (CI)?

Short answer:

• A multiple choice “test” that examines, in visual and non-technical terms, the most basic concepts of a foundational course. Often administered pre- & post- instruction.

• It evaluates what students *actually believe*, their tacit understanding, or personal interpretation (or lack of interpretation) of those fundamentals, typically represented by equations.

*No calculations*
Example mechanics problem:

A steel ball is attached to a string and is swung in a circular path in a horizontal plane as illustrated in the accompanying figure.

At the point P indicated in the figure, the string suddenly breaks near the ball. If these events are observed from directly above as in the figure, which path would the ball most closely follow after the string breaks?
Example mechanics problem:

The figure depicts a hockey puck sliding with constant speed $v_0$ in a straight line from point "a" to point "b" on a frictionless horizontal surface. Forces exerted by the air are negligible. You are looking down on the puck. When the puck reaches point "b," it receives a swift horizontal kick in the direction of the heavy print arrow. Had the puck been at rest at point "b," then the kick would have set the puck in horizontal motion with a speed $v_k$ in the direction of the kick.

Which of the paths below would the puck most closely follow after receiving the kick?

(A)  
(B)  
(C)  
(D)  
(E)

Force Concept Inventory 1995 [3]
Halloun and Hestenes observed:

• (1) **Common sense beliefs** about motion are generally incompatible with Newtonian theory. Consequently, there is a tendency for students to **systematically misinterpret** material in introductory physics courses.

• (2) Common sense beliefs are very stable, and conventional physics instruction does little to change them.

Halloun and Hestenes (1985) [4]
But…

The problems are so “easy”!

• How could the students not get them?
• The fact remains that, largely, they don’t.
• Instructors are typically “shocked.”

Mazur [5]
Halloun and Hastenes observed:

• (1) Common sense beliefs about motion are generally incompatible with Newtonian theory. Consequently, there is a tendency for students to systematically misinterpret material in introductory physics courses.

• (2) Common sense beliefs are very stable, and conventional physics instruction does little to change them.

Yet traditional instruction methods only weakly affect student’s deeply-held “common sense” beliefs.

Halloun and Hestenes (1985) [4]
Maybe you want some proof?

Like a comprehensive of study maybe of thousands of students, numerous professors, at colleges and universities, even high schools, applying a variety of teaching strategies?
“Interactive Engagement” (IE) methods designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors.

“Traditional” courses that make little or no use of IE methods, relying primarily on passive-student lectures, recipe labs, and algorithmic problem exams, as reported by instructors.

Score 12/30 (40%), dashed green line; retest 20/30 – a gain of 6, percent gain of 6/18 (33%), red circle. Random guessing score for each of these five-alternative multiple-choice tests is (6/30) or 20%.
Concept Inventories

• Can be used to evaluate *teaching methods* and identify specific and persistent *misconceptions* students hold.

• What makes a concept inventory special?
  – Constructed by a team of instructors
  – Wrong answers (distractors) matter as much as the right!
  – Validated for relevance, reliability, repeatability
  – Elicit deep conceptual analyses . . . to teach the teachers!
Exquisitely detailed analysis

Of Concepts

“Table I.
Newtonian Concepts in the Inventory.

<table>
<thead>
<tr>
<th>Taxonomy</th>
<th>Inventory Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>0. Kinematics</td>
<td></td>
</tr>
<tr>
<td>– Velocity discriminated from position</td>
<td>20E</td>
</tr>
<tr>
<td>– Acceleration discriminated from velocity</td>
<td>21D</td>
</tr>
<tr>
<td>– Constant acceleration entails parabolic orbit</td>
<td>23D…</td>
</tr>
<tr>
<td>– changing speed</td>
<td>25B</td>
</tr>
<tr>
<td>– Vector addition of velocities</td>
<td>(7E)</td>
</tr>
<tr>
<td>I. First Law</td>
<td></td>
</tr>
<tr>
<td>– ...</td>
<td></td>
</tr>
<tr>
<td>2. Second Law</td>
<td></td>
</tr>
<tr>
<td>3. Third Law</td>
<td></td>
</tr>
<tr>
<td>4. Superposition Principle</td>
<td></td>
</tr>
<tr>
<td>5. Kinds of Force&quot;</td>
<td></td>
</tr>
</tbody>
</table>

Of Misconceptions

“Table II.
A Taxonomy of Misconceptions Probed by the Inventory. Presence of the misconceptions is suggested by selection of inventory item.

<table>
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</tr>
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<tbody>
<tr>
<td>0. Kinematics</td>
<td></td>
</tr>
<tr>
<td>– Kl. position-velocity undiscriminated</td>
<td>208,C,D</td>
</tr>
<tr>
<td>– K2. velocity-acceleration undiscriminated</td>
<td>20A…</td>
</tr>
<tr>
<td>– K3. nonvectorial velocity composition</td>
<td>7C</td>
</tr>
<tr>
<td>1. Impetus</td>
<td></td>
</tr>
<tr>
<td>– ...</td>
<td></td>
</tr>
<tr>
<td>2. Active Force</td>
<td></td>
</tr>
<tr>
<td>3. Action/Reaction Pairs</td>
<td></td>
</tr>
<tr>
<td>4. Concatenation of Influences</td>
<td></td>
</tr>
<tr>
<td>5. Other Influences on Motion</td>
<td></td>
</tr>
<tr>
<td>– Resistance &amp; Gravity”</td>
<td></td>
</tr>
</tbody>
</table>

Hestenes, Wells, Swackhamer (1992) [7]
Remember –

Sir Isaac Newton was a genius!

This stuff is not obvious – it just is powerful TRUTH. So powerful, that once you understand it, it is easy to mistake it for SIMPLE.
So how can concept inventories help engineering education?

Or more specifically, how can this help *mechanical* engineering education?

Or rather, how can concept inventories help YOU teach mechanical engineering fundamentals like ME 240 – Fluid Mechanics?
Halloun and Hastenes (might have) observed:

• (1) Common sense beliefs about motion are generally incompatible with Newtonian theory. Consequently, there is a tendency for students to systematically misinterpret material in introductory physics and fundamental engineering courses.

• (2) Common sense beliefs are very stable, and conventional physics engineering instruction does little to change them.

*Italics mine.*
Element Two:

Engineering Education Research with Resonance

—a foundation for an $E^3$ education—
Major elements of a comprehensive strategy:

- Identify and distill core technical competencies, ideally with a team of peers. Test and/or adapt a CI.
- Interview students & extract common misconceptions.
- Develop and share adaptable teaching tools and approaches that can be PROVEN, using pre and post CI testing, to impact conceptual comprehension.
- Improve curriculum relevance (professional skills, too) and efficiency, then reduce overall prescribed hours!
- Encourage and integrate non-engineering course work.
Concept Inventories and YOU

- Ethically identify and distill the core relevant mechanical engineering competencies.
- Interview and extract common misconceptions.

Then

- Develop and share adaptable teaching tools and approaches that are PROVEN to impact fluency and comprehension in mechanics, fluid mechanics, thermodynamics, heat transfer, etc…
Where can you start?

The Foundation Coalition, funded by NSF

- Statics
- Dynamics
- Force and Motion
- Fluid Mechanics
- Heat Transfer
- Strength of Materials
- Thermodynamics
- Circuits
- Computer Engin.
- Electromagnetics
- Electricity
- Magnetism
- Signals and Systems
- Waves
- Chemistry
- Materials
- Statistics
- Others?

http://foundationcoalition.org/home/keycomponents/concept/index.html
What else?

• Test the tests for yourself! Assess their relevance for your constituents.
• Talk to your peers – in your department, across the country, around the globe.
• Talk to your students. What are they thinking? What do they really understand?
• Perform Think Aloud* evaluations/interviews.
• Adapt your own CI, if necessary. Validate and share it.
• Communicate your experiences and insights, successes and frustrations back to both the EnginEd and MechEngEd communities!
Don’t be disheartened!

• Your students’ results will probably not thrill you.
• Rise to the challenge.
• Get guidance!
• Build learning communities at your institutions or through your research societies to tackle specific topical areas.
• Develop expertise in your subset of misconceptions.
• Experiment responsibly and help build a literature base that will inform others.
One good “nuts and bolts” Interactive Engagement resource:


– Focused toward physics instruction
– But with LOTS of overlap and relevant engineering examples.
– See also: mazur-www.harvard.edu/education/educationmenu.php

Mazur [5]
An E³ engineering education –

Core fundamentals taught & learned

ETHICALLY EFFECTIVELY and EFFICIENTLY

builds the skills and leaves time for students to develop deep knowledge of themselves; physics, technology and design; human nature, the environment, history, and the globe and envision a sense of how they can and will impact the future and, hopefully, the public good.
Knowledgeable, Independent, Open-minded, Useful, Honorable, ENGINEER LEADERS

...who hold paramount the safety, health and welfare of the public... and conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession.

COMPETENCE  CREATIVITY  CONFIDENCE  COURAGE
Let’s give them what they’ll need to bring us all home safely.
References


