Building Computational Thinking at Top Universities

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MathWorks
Foundation: Computational Thinking
What Is Happening Elsewhere

MOOC

Computation

Inverted classroom

Collaboration

Visualization

Integrated curriculum

On-line learning

UNIVERSITY OF CAMBRIDGE

MIT

Imperial College London
Computational Thinking

A Thought Process to Formulate Problems and Solutions

Decomposition

Abstraction

Pattern Recognition

Algorithms
Where Computational Thinking Fits

Computational Thinking

Reading  Writing  Arithmetic
Computational Thinking is Important

"Computational thinking is a fundamental skill for everyone, not just for computer scientists."

Dr. Jeannette Wing, Vice President of Microsoft Research
Former Department Head of CS at Carnegie Mellon University

“Coding teaches me to think in a logical way”

Trinity School high school student
Accepted at MIT
How Math is introduced in the curriculum

How Computational Thinking is introduced

Traditional Approach to Teaching
The Future of How Computational Thinking Will be Taught

How Math is introduced in the curriculum

How Computational Thinking could be taught
How Top Universities Build Computational Thinking with MATLAB

1. Supplementing pen and paper
   Imperial College

2. Using on-line learning
   MIT

3. Integrating usage across classrooms
   MIT & University of Cambridge
1. Supplementing pen and paper

Visualization
The Mathematics Laboratory
Imperial College London, Bioengineering

1. Lecture (YouTube / live)
2. Pen and paper study group
3. MATLAB laboratory
4. Formal assessment

MATLAB to complement Mathematics teaching
• Brings Mathematics to life
• Engagement of brighter students
• Reinforcement learning
From Symbolic to Multi-Paradigm Solutions

- Start with Symbolic Math
- Reinforce hand-calculations
- Move to multi-paradigm solutions for real engineering problems

```
>> g = 10, mass = 2000
  g =
    10
  mass =
    2000
>> m = [cos(deg2rad(10)),
        cos(deg2rad(100)),
        sin(deg2rad(10)),
        sin(deg2rad(100))]
  m =
    0.9848  -0.1736
    0.1736   0.9848

>> inv(m)*[0 ; mass*g]
  ans =
    1.0e+04 *
    0.3473
    1.9696

>> ans(1)/315
  ans =
    11.0253
```
2. Using on-line learning

On-line course
Was a paper and pencil class
Moved the material to edX as a MOOC
Material is evolving through a constant cycle of residential classes and public MOOC offerings
**Different style of learning: Written Lecture Notes**

**Axisymmetric Shafts in Torsion**

**Loading Conditions on each Section \( x \)**

Applied loading only around the axis \( x \) of the shaft.

The only internal resultant at any sections \( x \)

is the axial torque \( \tau(x) \).

**Find \( \tau(x) \) along the bar (axial torque diagram) by cutting the bar at \( x \) and imposing moment \( x \) equilibrium.**

For the example shown, equilibrium at \( x \) gives:

for \( x < x_0 : \sum M_x = 0 = - \tau(x) + Q^C + Q^B \Rightarrow \tau(x) = Q^C + Q^B \)

for \( x > x_0 : \sum M_x = 0 = - \tau(x) + Q^C \Rightarrow \tau(x) = Q^C \)

And the entire axial torque diagram is:

For distributed loading \( t(x) \), with \( t(x) \) [in (N*m)/m =N] 

with right hand rule along \( x \), obtain the torque \( \tau(x) \) by integrating \( t(x) \) along the shaft. For the shaft shown:

\[
\tau'(x) = \int_t t(x) dx
\]

The differential relationship between the distributed torque \( t(x) \) and the axial resultant \( \tau(x) \) is

\[
\frac{d\tau(x)}{dx} = -t(x)
\]
Different style of learning: Short Video Lectures

shafts in Torsion

Axial Loading
Cross section displacement

\[ \varepsilon_a = \frac{d \varepsilon_a}{dx} = \varepsilon_a(x) \]
Concept Questions in reading and video

E6_2_1

(1 point possible)
Obtain a symbolic expression for the effective section stiffness of the shaft, \((GI_p)_{Eff}\), in terms of \(R_0\) and \(G_0\) (enter the solution)

\[(GI_p)_{Eff} = \, ?\]

CHECK

E6_2_2

(1 point possible)
Obtain a symbolic expression for the \(x\)-rotation field along the shaft, \(\varphi(x)\), in terms of \(R_0\), \(G_0\), \(L\), \(Q\), and \(x\). (Note the direction of \(x\) in the figure):

\[\varphi(x) = \, ?\]

CHECK
Online recitations

VR7_1a

For the beam, \( \mathcal{M}(x) \), the maximum

\[ \mathcal{M}(x) = \ldots \]

\[ (4 \text{ pt}) \]

\[ \mathcal{M}^+_{\text{max}} = \ldots \]

Start of transcript. Skip to the end.

PROFESSOR: Hi everyone, and welcome back to 2.01x recitation. In this segment, we're going to do a number of examples of finding the moment diagram for beams under various loading conditions. So let's get started with a simple one. So we're just going to have our beam supported by two pins. So we've got something like this.
MATLAB Problem Sets

E6_1: SHFAR STRAIN AND SHFAR STRESS IN A COMPOSITE SHAFT
E6_1_2
E6_1_4X

(1/1 point)

Use the MATLAB window below to verify your solution to part (4) above: obtain the values of the maximum shear stress in the sleeve $\tau_{s,max}$ and in the core $\tau_{c,max}$ on each section $z_i$ for $0 \leq z_i \leq L$. For $\tau_{s,max}$ and $\tau_{c,max}$ make sure you have the numeric values in MPa, and use corresponding MATLAB variables $\text{tau}_c_{max}$ and $\text{tau}_s_{max}$ in your script. EXTRA STEP: Try to obtain a plot with both curves, $\tau_{s,max}$ and $\tau_{c,max}$ as a function of position $x$ along the shaft (the plotting task is not checked). Do the two curves cross at your predicted value $x^*$?

```matlab
17 Create variables representing the given quantities
L = 1; % in [m]
R0 = 0.01; % in [m]
G0 = 7069; % in [Pa]
Gc = 2*G0; % shear modulus of the core
16 e0 = 0.001; % shear modulus of the sleeve

R = linspace(0.01, 0.2, 20); % a vector of (20) x positions along the shaft

% Your code below
% re-use the same script of part 2x......

12 Ra = sqrt(2)*R0; % outer radius at A
13 RB = sqrt(5)*R0; % outer radius at B
14 R = Ra+(RB-Ra)*x/L; % a vector with outer radius of the shaft at each x position
15

Correct

Figure 1

NOTE: this is probably the MOST challenging problem you have seen so far. I strongly suggest you do the three recitation problems before you try this one. The MATLAB scripts are quite long, and use tricks you might not have seen before, but they are quite nifty and you might like them! Try doing as much work as you can before you reveal the solutions, and try playing with the MATLAB answer scripts to understand how they work.
3. Integrating usage across classrooms

Integrated curriculum
MIT – Department of Brain and Cognitive Sciences

- Request from industry and graduate research
  - None of undergraduate courses taught computation
  - Moved to introduce quantitative material earlier

- Hired instructor for a transition to more computation (MATLAB) in courses
  - 9.40 Introduction to Neural Computation (required UG)
  - 9.54 Computational Aspects of Biological Learning (elective UG)
  - 9.011 Systems Neuroscience (required G – level setting incoming student knowledge)

- MATLAB Bootcamp, office hours

Taken from: MIT OCW 9.29
University of Cambridge
Biological Sciences

- Natural Science Course at Cambridge Biological Sciences stream
  - MATLAB Course complement Math (Year 1)
  - Reinforcement & math modelling in Plant & Microbial Science (Year 2)
  - Genetics and Zoology using the modelling skills (Year 3)
  - Systems Biology – Modelling techniques (Year 4 or Masters)
Laboratory Exercises

- Word problems
- Apps
- Scripts & functions
- Visualizations

Task 4

Suppose instead the patient is able to take an oral pain killer. A tablet containing 30mg of the same pain-relief agent is administered. The absorption rate of the drug from the gut into the blood plasma $b = 0.24$ per hour and the elimination rate of the drug $k = 0.28$ per hour.

(a) Draw a schematic diagram to illustrate the new system and write down the governing equations and fluxes.

(b) Solve the equation for the absorption compartment and insert the solution into the central compartment. You should get:

$$\frac{dC_1}{dt} = bV_1C_2e^{-kt} - kV_1C_1 = bV_1C_2 - kV_1C_1$$

Where $D$ is the dose of drug. $V_2 = V_d = 210$ liters.

(c) Modify your script code to solve this model.

Hints:
- (i) make sure you have adjusted component 2 of your code correctly:
  $V_d = 210$; % volume of distribution lites
  $Dose = 25*10^3$; % milligrams; 1000 gives micograms
  $C_{init} = 0$; % no drug in body at time 0 as oral dose
  $t = 0:0.15; % per hour
  $k = 0.28; % per hour
  $tau = 12; % time range over which to solve model (hours)
  $J_{in} = J_t(0); % influx
  $J_{out} = J_t(t); % efflux$

- (ii) make sure you have adjusted component 3 of your code correctly.

(d) How long does it take blood plasma concentration to reach therapeutic levels?
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Integrated Curriculum Builds **Depth** within the Domain

What about **Breadth**?
Is This Just About Engineering?

Schools and Colleges are Siloed by Nature

Real World Problems Are Multidisciplinary and Require Collaboration across Domains
What if Computational Thinking Was Commonplace?

Foundation: Computational Thinking

Cross-Collaboration
Computational Thinking – One Common Language

Integrated Curriculum → Integrated Campus

MATLAB Enabled Campus for Everyone, Anywhere