Optimization: It's Not Engineering Design Without It

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Overview

- Engineering design, technology education design, and the role of optimization
- Requisite skills and procedures for optimization
- Implementing optimization in technology education
- Outcomes of technology education with an engineering design focus

Engineering design defined

Engineering design is the application of technical knowledge, creativity, and an appreciation of the effects of a design on society and the environment.

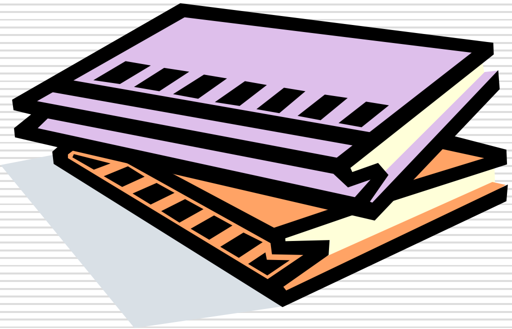
Engineering design focus

- Engineering is more understood and valued than technology education by the general populace
- Elevates the field of technology education to a higher academic and technological level
- Provides a solid framework to design and organize curriculum
- Provides an ideal platform for integrating mathematics, science, and technology
- Provides a focused curriculum which can lead to multiple career pathways for students

Four essential representations

1. Semantic – verbal or textual explanation of the problem
2. Graphical – technical drawing of an object
3. Analytical – mathematical equations utilized in predicting solutions to technological problems
4. Physical – constructing technological artifacts or physical models for testing and analyzing

Impact on teacher curriculum



- Core classes different
  - Higher levels of math
  - Physics and chemistry
  - Statics, dynamics, etc.
- Changes in technology teacher education courses
  - Added emphasis on analysis and optimization
  - Constraints included for hands-on learning activities

Design processes compared

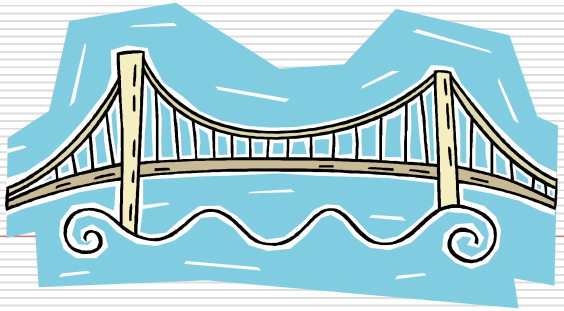
Technology Education Design Process	Engineering Design Process
Identifying the problem	Identify the need
Brainstorming	Define problem
Researching & generating ideas	Search for solutions
Identifying criteria	Identify constraints
Specifying constraints	Specify evaluation criteria
Exploring possibilities	Generate alternative solutions
Select an approach	**Analysis**
Develop a design proposal	**Mathematical predictions**
Building a model or prototype	**Optimization**
Testing & evaluating the design	**Decision**
Refining the design	**Design specifications**
Communicating results	Communication

Traditional technology education design problem

Using the balsa materials provided, design a 15 cm tall tower that weighs a maximum of 180 grams with an opening that a 2 x 4 can pass through that can support the maximum load possible.

Analysis and optimization

- What analysis used to build the
    - fastest CO_2 race car
    - strongest tower or bridge
    - highest flying rocket
- How much emphasis on engineering analysis when solutions are judged?
- Retooling needed?



What is optimization?

- Goal in a general sense is efficiency
- Problem solution is maximized for profit or minimized for loss
- Optimal product is one that most economically meets its performance requirements
- Often requires nonlinear algorithms solved using differential equations

Optimization and technology education

- Understand and apply the principles with limited calculus
- Surrogate models and approximations
  - Models that are less physically faithful but less computationally intensive
  - Approximations are algebraic summaries obtained from previous analyses
- “tool kit” for those with limited math

Examples of optimization

- Still a work in progress
- Challenging due to disparate levels of mathematical capabilities
- Increased application of math and science in materials to be developed
- Strategies needed to communicate optimization to all students, even those with limited math / science

Optimizing bridge design

Would these materials work to build this bridge?

Issues to consider

- Type of structure
- Type of materials
- Cost of materials
- Size of members
- Section size
- Availability of materials
- Worker knowledge
- Types of loads
- Type of structure

Type of structure

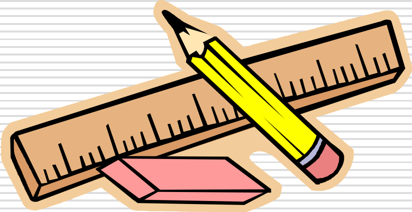
- Truss (30-400 ft span)
- Rafters or beams (less than 100 ft span)
- Suspension bridge (very long spans; > 400 ft)
- Span is equal to the distance from support to support

Type of material

- Steel – good in tension and compression
- Reinforced concrete – good in compression
- Wood – short spans; good in tension and compression
- Aluminum – good in tension and compression
- Composite sections (reinforced concrete and steel)
- Wood composites – stronger than natural wood

Size of materials

- Height & width – limited on these dimensions due to selected member sizes
- Standard sizes – common sections (wood, steel, aluminum)
- Custom sizes – unique to project

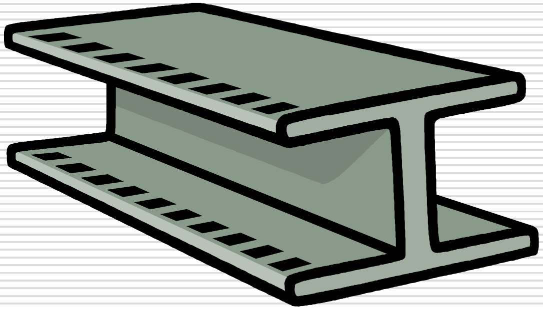


Cost of materials

- $ per yd^3 – concrete
- $ per lb – steel
- $ per board foot – wood

Availability of materials

- Location of nearest vendor
- What materials carried "in-stock"
- Requirements for "special orders"
- What can be delivered



Variable section size

- Fewer members reduces construction errors (advantage)
- Fewer members means less vendor problems (advantage)
- Multiple members the same size results in excess strength in some areas of structure (disadvantage)

Worker knowledge of materials

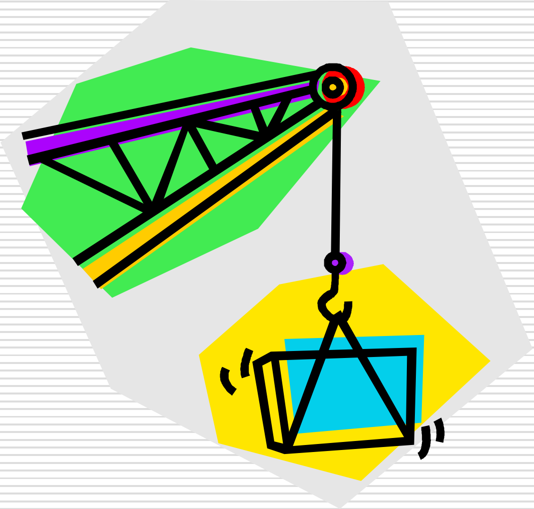
- Specialized construction techniques requires more of workers
- What workforce is available?
- Level of experience with materials and fabrication design
- Cost of labor is influenced by considerations already discussed

Lots of decisions

- Do engineers really go through this thought process?
- Taught this in their schooling
- They do use this process
- Novice to expert continuum influences awareness of process
- … but where is the math?

Types of loads

- Dead load – weight of members
- Live load – forces caused by use
- Snow
- Wind
- Earthquake
- Impact



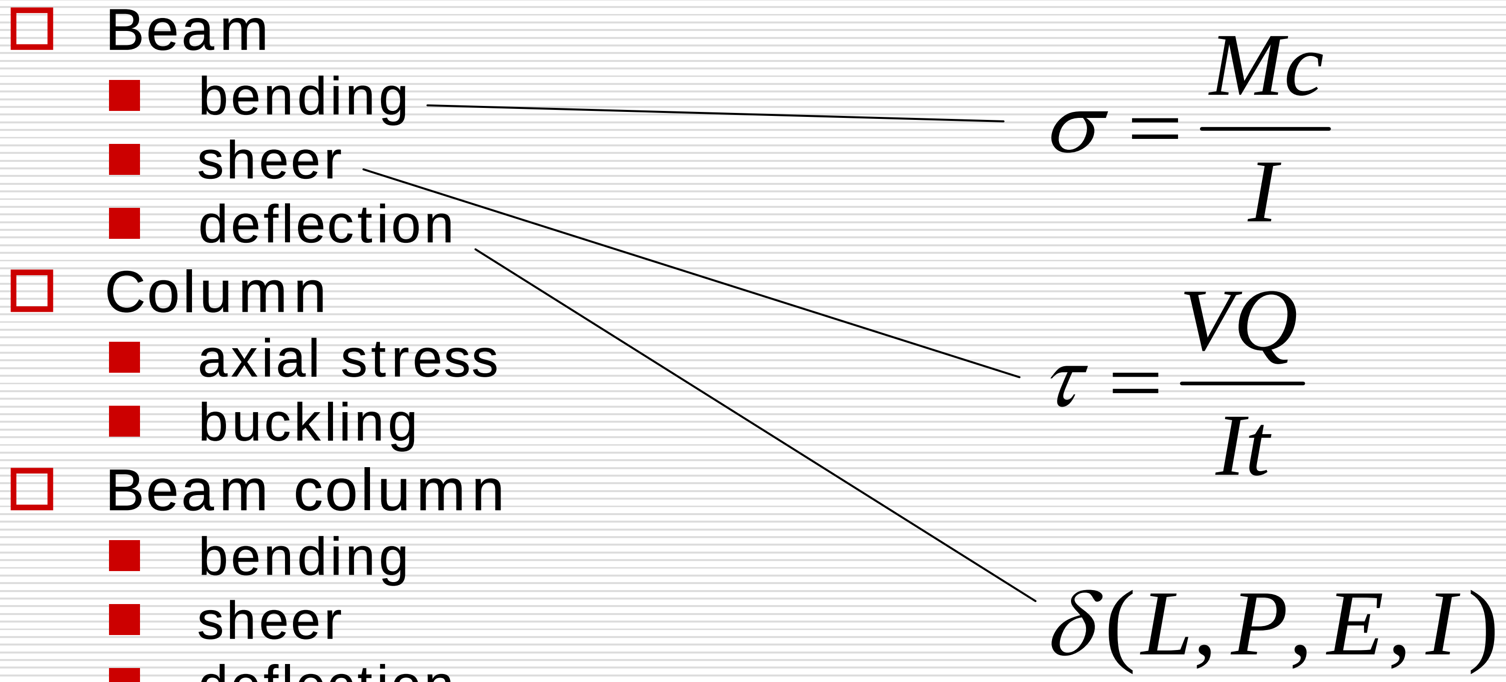
Type of materials

- Design dictated by standards
- Steel – American Institute of Steel Construction (AISC) code manual for steel construction
- Concrete – American Concrete Institute (ACI) code
- Wood – National Design Specification (NDS) or American Institute of Timber Construction (AITC)

Forces on individual members

- Tensile load
- Compression load
- Bending moment
- Shear load
- Static load

Type of member



- Beam
  - bending
  - sheer
  - deflection
- Column
  - axial stress
  - buckling
- Beam column
  - bending
  - sheer
  - deflection
  - axial stress
  - buckling

$$\sigma = \frac{Mc}{I}$$

$$\tau = \frac{VQ}{It}$$

$$\delta(L, P, E, I)$$

Engineering design …

- includes optimization as key process
- describes a specific approach to designing technological artifacts
- involves semantic, graphical, analytical and physical representations

Type of structure

Size of members

Section size

Cost of materials

Type of materials

Worker knowledge

Types of loads

Type of structure

Availability of materials

Key suggestions

- Add an upper parameter on load – don’t limit criteria to “strongest possible”
- Place emphasis on the design process
- Help students understand complexities of optimization
  - Lots of decisions
  - Interrelated decisions

Hybrid vehicle example

- The price of gasoline is skyrocketing
- Hybrid vehicles get great gas mileage
  - 2005 Prius – 55 mpg (comb)
  - 2005 Insight – 56 mpg (comb)
  - 2005 Civic – 48 mpg (comb)
  - 2005 Accord – 32 mpg (comb)
- Is a hybrid vehicle a “good buy” for the money?

Comparison to conventional vehicle

- MSRP
  - Prius – $20,875
  - Civic EX – $18,160
  - Camry – $20,955
  - Accord EX – $20,725
- Exterior length & width most like Civic
- City mpg Prius 60 / Civic 31
- Highway mpg Prius 51 / Civic 38

Optimization

- Product that most economically meets performance requirements
- City mpg for most conservative figures
- $2715 price difference
- Yearly fuel cost @ 15,000 mi / year and $2 / gallon
  - Prius – $500
  - Civic – $968
- $2715/$468=5.8 years

Other factors to consider

- Yearly mileage
- Interior space
- Cargo space
- Maintenance requirements and availability
- Performance
- Aesthetics

Relevance for K-12 education

- Cultivates an analytical approach to solving practical problems
- Provides real-world applications for mathematics and science
- Engineering design addresses *Standards for Technological Literacy*
- Enhances benefits of technology education for student achievement

Summary & conclusions

- Engineering design can enhance technology education curriculum
- Optimization is an essential element of an engineering design focus
- Changes are needed to include opportunities for optimization
- Student problems need to be defined with optimization in mind

Contact information

URL for this presentation:
www.coe.uga.edu/engineer/presentations/optimization.pdf
Other sources of interest:
www.coe.uga.edu/engineer
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