Framework for P-12 Engineering Learning

ENSURING THAT EVERY CHILD IS GIVEN THE OPPORTUNITY TO THINK, LEARN, AND ACT LIKE AN ENGINEER

MARCH 12, 2020

@AEEngEdu
Overview

- AE3 Mission & Goals (Our Story)
- Framework Development
- Engineering Literacy
- Progressions of Learning
- Executive Summary
The Team

@tannerhuffman

Advancing Excellence in P-12 Engineering Education
AE3 Vision

Ensure every child is given the opportunity to think, learn, and act like an engineer.

Engineering Literacy for ALL + Career Pathways
AE3 Mission

Cultivate a vibrant "garden" in which to "grow" projects that advance a coherent, equitable, age-appropriate and compulsory study of engineering in P-12 schools.
AE3 Goals

- A Defined & Cohesive Guide
- ‘Truth in advertising’
- Support for Quality P-12 Engineering Education
  - Credentialing
  - Assessment
  - Endorsement
- Enhance Access
Framework for P-12 Engineering Learning

A Defined & Cohesive Educational Foundation for P-12 Engineering

Identifies the "Know", "Do" and "Act"

Years of Research & Stakeholder Engagement

Shared Focus, Vision, & Research Agenda
Framework for P-12 Engineering Learning

Define & Articulate Student Expectations/Progressions

Guide the development of standards that in turn guide:
- Engineering-related curriculum
- Instruction
- Assessment
- Credentialing
- Professional Development
Sponsors

Advancing Excellence in P-12 Engineering Education
WHY

• Current Initiatives are Promising

• A Clear Vision/Roadmap Eludes Educators

• Little is Known About
  • How children progress through engineering learning.
  • How engineering programs contribute to general literacy.

• Consistency can ensure a more equitable approach
## History of Technology Education in U.S.

<table>
<thead>
<tr>
<th>INCEPTION</th>
<th>1876</th>
<th>1896</th>
<th>1910</th>
<th>1947</th>
<th>2009</th>
</tr>
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<tbody>
<tr>
<td>IDENTITY</td>
<td>MANUAL TRAINING</td>
<td>MANUAL ARTS</td>
<td>INDUSTRIAL ARTS</td>
<td>TECHNOLOGY EDUCATION</td>
<td>TECHNOLOGY &amp; ENGINEERING EDUCATION</td>
</tr>
</tbody>
</table>

### Inception Dates

- **1876**: Inception of Manual Arts
- **1896**: Inception of Industrial Arts
- **1910**: Inception of Technology Education
- **1947**: Inception of Technology & Engineering Education
- **2009**: Inception of Technology Education

### Key Events

- **1966**: A Rationale and Structure for Industrial Arts Subject Matter
- **1970**: The Maryland Plan
- **1981**: Industrial Arts Program for the Junior High School
- **1990**: A Conceptual Framework for Technology Education
- **1996**: Technology for All Americans
- **2000**: Standards for Technological Literacy

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*Advancing Excellence in P-12 Engineering Education*
A Need

Timing is Right? A Social Need?
Integrate w/others? (= Vehicle for Science)

Since 2009, NAE Reports have recommended:
- Agreed Upon Content
- Framework or Taxonomy
- Age-Appropriate Learning Progressions

Creation of a new program?
Lack of Coherence (Too Few Exposed)
Trained Teachers?
Scaffolding, Depth, & Intentional Content?
<table>
<thead>
<tr>
<th>Sub-Concepts</th>
<th>Structural Analysis</th>
<th>Statics</th>
<th>Project Management</th>
</tr>
</thead>
</table>
| Physical Properties of Building Materials | • Resultants of force systems  
• Equivalent force systems  
• Equilibrium of rigid bodies  
• Frames & trusses  
• Centroid of area  
• Area moments of inertia | • Initiating & Planning  
• Scope, Time, & Cost Management  
• Risk, Quality, Teams, & Procurement  
• Product Life Cycle Management |                                                                                |
| Deflection                  |                                                                                      |                                                                         |                                                                                   |
| Deformations                |                                                                                      |                                                                         |                                                                                   |
| Column & Beam Analysis      |                                                                                      |                                                                         |                                                                                   |
| Implementation of Design Codes |                                                                                      |                                                                         |                                                                                   |
| Figure 1. Engineering content for the example tower activity. | | | |
An Opportunity

Generic to Specific (Too Broad)
Usable & Digestible
Diverse Participation
The End in Mind – Schools
A Models to be Tested
Towards a Framework for Engineering Learning

White Paper from the Advancing Excellence in P12 Engineering Education Research Collaborative
Development Process

UNCERTAINTY / PATTERNS / INSIGHTS

CLARITY / FOCUS

RESEARCH

CONCEPT

原型

设计

Advancing Excellence in P-12 Engineering Education
Development Process

• **PHASE 1: Research & Investigation**
  • Fact finding research (literature Review, Textbook)
  • Investigation of the epistemological foundations
  • Where it is and where is should be?

• **PHASE 2: Development & Testing**
  • Series of action-oriented symposia
  • Establish concepts & practices for engineering literacy
  • Develop examples to be tested
  • Pilot implementation sites to validate components

• **PHASE 3: Synthesis & Writing**
  • Assembling the three years of input from the engaged community into a coherent framework with
  • Feedback from ASEE representatives
Phase 1

Foundation for Coherent Content Framework

• Fact finding research
  • Taxonomy Structure

• Modified Delphi Study
  • Round 1: Concept discovery
  • Round 2: Concept prioritization
  • Round 3: Concept rating
  • Final Round: Concept Refinement
<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Content Areas</th>
<th>Number of Core Concepts</th>
<th>Number of Sub-Concepts</th>
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</thead>
<tbody>
<tr>
<td>Knowledge</td>
<td>Mechanical</td>
<td>8</td>
<td>48</td>
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<tr>
<td></td>
<td>Electrical</td>
<td>9</td>
<td>44</td>
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<tr>
<td></td>
<td>Civil</td>
<td>8</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>Chemical</td>
<td>8</td>
<td>39</td>
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<tr>
<td>Practices</td>
<td>Engineering Design</td>
<td>9</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>Material Processing</td>
<td>9</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>Quantitative Analysis</td>
<td>9</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Professional Conventions</td>
<td>6</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td><strong>TOTAL</strong></td>
<td><strong>66</strong></td>
<td><strong>313</strong></td>
</tr>
<tr>
<td>Mechanical Engineering Sciences for Mechanical Engineering</td>
<td></td>
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<tr>
<td>---</td>
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</tbody>
</table>
| - Force Systems  
- Equilibrium  
- Inertia  
- Friction  
- Centroids & Moments  
- Particles  
- Rigid Bodies  
- Newton’s Second Law  
- Work and Energy  
- Impulse-momentum  |
<table>
<thead>
<tr>
<th>Electrical Engineering Sciences for Electrical Engineering</th>
</tr>
</thead>
</table>
| - Properties of Materials (Chemical, Electrical, Mechanical and Thermal)  
- Current, Voltage, Charge, Energy, & Power  
- Forces (e.g. charges, conductors)  
- Voltage and Work  
- Electrical Power  |
<table>
<thead>
<tr>
<th>Civil Engineering Sciences for Civil Engineering</th>
</tr>
</thead>
</table>
| - Force  
- Equilibrium  
- Inertia  
- Friction  
- Centroids & Moments  
- Rigid Bodies  |
<table>
<thead>
<tr>
<th>Chemical Engineering Sciences for Electrical Engineering</th>
</tr>
</thead>
</table>
| - Applications of Inorganic Chemistry  
- Applications of Organic Chemistry (e.g. Biofuels)  
- Chemical, Electrical, Mechanical and Physical Properties (including potential hazards)  
- Material Types and Compatibilities  
- Corrosion  
- Membrane Science  |
<table>
<thead>
<tr>
<th>Chemical Reaction &amp; Catalysis</th>
</tr>
</thead>
</table>
| - Reaction rate, Rate Constant, & Order  
- Conversion, Yield, & Selectivity  
- Chemical Equilibrium |
<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Content Areas</th>
<th>Number of Concepts</th>
<th>Number of Sub-Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge</td>
<td>Engineering Sciences</td>
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<td></td>
<td>Engineering Mathematics</td>
<td>4</td>
<td>18</td>
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<tr>
<td></td>
<td>Technical Applications</td>
<td>12</td>
<td>43</td>
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<tr>
<td>Practices</td>
<td>Engineering Design</td>
<td>9</td>
<td>31</td>
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<tr>
<td></td>
<td>Material Processing</td>
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<td>35</td>
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<tr>
<td></td>
<td>Quantitative Analysis</td>
<td>9</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>Professionalism</td>
<td>6</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>58</td>
<td>241</td>
</tr>
</tbody>
</table>
Phase 2

Action Oriented Symposia
(Engaged Community)
Focused Topics
1\textsuperscript{st} AE3 Symposium

Establish a Content & Progressions of Learning
BCPS Curriculum Writing
Introduction

Computational thinking is a problem-solving technique traditionally employed by computer scientists to develop computer applications. However, computational thinking practices are now believed to be applicable to other fields (Google for Education, 2018), specifically those related to engineering and technology. Accordingly, the Advancing Excellence in P-12 Engineering Education (AEEE) (2018) project identified computational thinking as a core engineering concept to create a foundation for students to conduct the quantitative analyses that engineers and other related professionals perform. Likewise, the Committee for the Workshops on Computational Thinking contends that computational thinking is necessary for people to develop efficient and automated physical design solutions as well as visualizations of design concepts and computational scientific models (NRC, 2011). These abilities, which also include thinking critically about complex problems, generating creative solutions, and communicating solutions effectively, are now considered necessary at all levels of scholarship.

By Greg J. Strimel, Abby Morehouse, Scott R. Bartholomew, Colin Swift, and Jonathan Woessner

This article will provide an example instructional activity for fostering computational thinking while also addressing core engineering concepts in electronics using programmable E-textiles.

Figure 1. Student sewing an electrical circuit for a wearable device using conductive thread and E-textiles.
BCPS Curriculum Writing
3rd AE3 Symposium

The Engineering Framework

- Inform the Framework
- Provide Exemplars (The Best Current State)
- Collect Feedback (Envisioned State)
Phase 3

• Framework to inform:
  • What authentic engineering is...

• Development of learning progressions and/or standards

• Provide curriculum endorsement, create assessments, and industry credentials.

• Ultimately help create a coherent and hopefully compulsory school subject
Towards a Framework for P-12 Engineering

**Framework** - Define educational goals and purpose; inform curriculum development.

**Curriculum** - Identifies the specific content and desired learning outcomes; informs teaching practice.

**Instruction** - Translate curriculum into the local context; informed by theory, craft knowledge, and understanding of student needs.

**Students** - Recipients of and active partners in the educational process.
Phase 3

• Guiding Principles of the Framework
  ◦ Equity Remains at the Forefront
  ◦ Authenticity to Engineering
  ◦ Depth over Breath
  ◦ Children are Natural Problem Solvers
  ◦ Making is a Form of Active Learning
  ◦ Connect w/Interests, Culture, & Experiences
Framework Chapters

1. A Vision & Rationale for P-12 Engineering
2. Equity Through Engineering Education
3. Development Process & Navigate the Framework
4. Defining Engineering Literacy: Content & Structure
5. Guidelines for Implementation
6. Evaluating Engineering Learning
7. Beyond Engineering Literacy
Engineering Literacy

1. **Engineering Habits of Mind** that students should develop over time through repetition and conditioning,

2. **Engineering Practices** in which students should become competent, and

3. **Engineering Knowledge** that students should be able to recognize and access to inform their engineering practice.
Engineering Literacy for ALL

End of secondary school all students should be provided the learning experiences necessary to

1. Orient their ways of thinking by developing Engineering Habits of Mind

2. Competently enact authentic Engineering Practices

3. Engineering Knowledge dimension is defined as the scientific, mathematical, and technical concepts that students should appreciate and be able to draw upon, when appropriate, to better perform the practices of engineering.
Engineering Learning

Primary (PK-2)
Elementary (3-5)
Middle (6-8)
High (9-12)

Practices
Knowledge
Engineering Literacy

Engineering Habits of Mind
- Optimism
- Persistence
- Collaboration
- Creativity
- Conscientiousness
- System Thinking

Engineering Practices
- Engineering Design
- Material Processing
- Quantitative Analysis
- Professionalism

Engineering Knowledge
- Engineering Sciences
- Engineering Mathematics
- Engineering Technical Applications
<table>
<thead>
<tr>
<th>Habit of Mind</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimism</td>
<td>Engineers, as a general rule, believe that things can always be improved. Just because it hasn’t been done yet, doesn’t mean it can’t be done. Good ideas can come from anywhere and engineering is based on the premise that everyone is capable of designing something new or different.</td>
</tr>
<tr>
<td>Persistence</td>
<td>Failure is expected, even embraced, as engineers work to optimize the solution to a particular challenge. Engineering – particularly engineering design – is an iterative process. It is not about trial and error. It is trying and learning and trying again.</td>
</tr>
<tr>
<td>Collaboration</td>
<td>Engineering successes are built through collaboration and communication. Teamwork is essential. The best engineers are willing to work with others. They are skilled at listening to stakeholders, thinking independently, and then sharing ideas.</td>
</tr>
<tr>
<td>Creativity</td>
<td>Being able to look at the world and identify new patterns or relationships or imagine new ways of doing things is something at which engineers excel. Finding new ways to apply knowledge and experience is essential in engineering design and is a key ingredient of innovation.</td>
</tr>
<tr>
<td>Conscientiousness</td>
<td>Engineering has a significant ethical dimension. The technologies and methods that engineers develop can have a profound effect on people’s lives. That kind of power demands a high level of responsibility to consider others and to consider the moral issues that may arise from the work.</td>
</tr>
<tr>
<td>System Thinking</td>
<td>Our world is a system made up of many other systems. Things are connected in remarkably complex ways. To solve problems, or to truly improve conditions, engineers need to be able to recognize and consider how all those different systems are connected.</td>
</tr>
</tbody>
</table>
Engineering Habits of Mind

**Engineering Literacy Dimension:** Engineering Habits of Mind
**Engineering Habit of Mind:** Collaboration

*Collaboration* is the ability to work with others to complete a task and achieve desired goals. A collaborative habit of mind enables an engineering professional to connect with and draw upon the perspectives, knowledge, and capabilities of others to best achieve a common purpose. This *Engineering Habit of Mind* is important to *Engineering Literacy* as most engineering projects are undertaken as a team and successful solutions require the participation from team members with diverse backgrounds. Engineering successes are built through a willingness to work with others, listen to stakeholders, think independently, and share ideas collaboratively. Therefore, by the end of secondary school, engineering literate students should be collaborative throughout the course of a team-based project to leverage diverse perspectives in successfully completing designated tasks.

- **Defining the Habit**
- **Providing Specificity to the Application of the Habit**
- **Detailing the Importance of the Habit to Engineering Related Professions**
- **Setting the Student Performance Expectation for Achieving Engineering Literacy by the end of Secondary School**
<table>
<thead>
<tr>
<th>Engineering Practices</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Engineering Design</strong></td>
</tr>
<tr>
<td>• Problem Framing</td>
</tr>
<tr>
<td>• Information Gathering</td>
</tr>
<tr>
<td>• Ideation</td>
</tr>
<tr>
<td>• Prototyping</td>
</tr>
<tr>
<td>• Engineering Graphics</td>
</tr>
<tr>
<td>• Decision Making</td>
</tr>
<tr>
<td>• Project Management</td>
</tr>
<tr>
<td>• Design Methods</td>
</tr>
<tr>
<td>• Design Communication</td>
</tr>
<tr>
<td><strong>Material Processing</strong></td>
</tr>
<tr>
<td>• Measurement &amp; Precision</td>
</tr>
<tr>
<td>• Manufacturing</td>
</tr>
<tr>
<td>• Fabrication</td>
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<tr>
<td>• Material Classification</td>
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<tr>
<td>• Joining</td>
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<tr>
<td>• Casting/Molding/Forming</td>
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<tr>
<td>• Separating/Machining</td>
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<tr>
<td>• Conditioning/Finishing</td>
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<tr>
<td>• Safety</td>
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<tr>
<td><strong>Quantitative Analysis</strong></td>
</tr>
<tr>
<td>• Computational Thinking</td>
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<tr>
<td>• Computational Tools</td>
</tr>
<tr>
<td>• Data Collection, Analysis, &amp; Communication</td>
</tr>
<tr>
<td>• System Analytics</td>
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<tr>
<td>• Modeling &amp; Simulation</td>
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<tr>
<td><strong>Professionalism</strong></td>
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<tr>
<td>• Professional Ethics</td>
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<tr>
<td>• Workplace Behavior/Operations</td>
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<tr>
<td>• Honoring Intellectual Property</td>
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<tr>
<td>• Impacts of Technology</td>
</tr>
<tr>
<td>• Role of Society in Technological Development</td>
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<tr>
<td>• Engineering-Related Careers</td>
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</tbody>
</table>
**Engineering Literacy Dimension:** Engineering Practices

**Engineering Practice:** Engineering Design

**Core Concept:** Problem Framing

*Problem Framing* is a process, which occurs early in and throughout the practice of *Engineering Design*, that involves outlining one’s mental interpretation of a problem situation by identifying the goals and essential issues related to developing a desired solution. This includes identifying design parameters to formulate a problem statement that (a) considers multiple perspectives, (b) removes perceived assumptions that unnecessarily limit the problem solving process, and (c) frames the design scenario in such a manner that helps guide the problem solving process. This core concept is important to the practice of *Engineering Design* as design problems are, by nature, ill-structured and open-ended. Therefore, by the end of secondary school, engineering literate students should be able to construct justified problem statements that highlight the key elements of a design scenario, including multiple perspectives, to guide the evaluation of trade-offs between multiple, and sometimes conflicting, goals, criteria, and constraints during a design project.
# Engineering Knowledge

<table>
<thead>
<tr>
<th>Engineering Sciences</th>
<th>Engineering Mathematics</th>
<th>Engineering Technical Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statics</td>
<td>Mass Transfer &amp; Separation</td>
<td>Electrical Power</td>
</tr>
<tr>
<td>Mechanics of Materials</td>
<td>Chemical Reactions &amp; Catalysis</td>
<td>Communication Technologies</td>
</tr>
<tr>
<td>Dynamics</td>
<td>Circuit Theory</td>
<td>Computer Architecture</td>
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<tr>
<td>Thermodynamics</td>
<td>Heat Transfer</td>
<td>Process Design</td>
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<tr>
<td>Fluid Mechanics</td>
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<td>Structural Analysis</td>
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<td>Environmental Considerations</td>
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<td>Hydrologic Systems</td>
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<td>Transportation Infrastructure</td>
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<td>Geotechnics</td>
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<td>Chemical Applications</td>
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<td>Mechanical Design</td>
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<td></td>
<td></td>
<td>Electronics</td>
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</tbody>
</table>
Engineering Knowledge concepts are auxiliary in nature

1. help students solve problems in a manner that is analytical, predictive, repeatable, and practical,

2. situate learning in an authentic engineering context

3. guide the development of engineering programs.
Engineering Literacy Dimension: Engineering Knowledge
Domain: Engineering Sciences
Auxiliary Concept: Mechanics of Materials

Mechanics of Materials concerns the mechanical behavior of deformable bodies when they are subjected to stresses, loads, and other external forces. This concept is important to Engineering Literacy, as it is the basis on which engineers select materials and modify their forms to create mechanical devices and systems. For example, the application of this knowledge enables professionals to predict structural failure by using Stress-Strain analyses and Young’s modulus to evaluate an object's deformation resulting from applied loads. Therefore, by the end of secondary school, engineering literate students should be able to, when appropriate, draw upon the knowledge of the Mechanics of Materials, such as (a) stress types and transformations, (b) material characteristics, (c) stress-strain analysis, and (d) material deformations, to analyze the properties, compositions, and behaviors of available, or needed, materials to solve problems in a manner that is analytical, predictive, repeatable, and practical.
Core Concept: Mechanics of Materials

Engineering students should understand various materials, their properties, and their behaviors, including stresses, equilibrium and deformation, when selecting them for solutions to design projects.

I can successfully choose a material within constraints for an engineering solution by understanding a material's characteristics, properties, composition, and behavior.

Sub Concept

Stress Type

Properties, characteristics and composition

Stress and Strain Analysis

Static Equilibrium

Material Deformation

1. I can explain the various ways that materials can be stressed (axial, bending, torsion, and shear).

2. I can calculate the various types of stresses for materials (axial, bending, torsion, and shear).

3. I can design an engineering solution while optimizing the various engineering stresses (axial, bending, torsion, and shear).

4. I can generate and justify a material selection based on its characteristics, properties, and composition.

5. I can generate and utilize a data-driven stress-strain diagram for materials.

6. I can design and optimize a system that will be able to maintain its static equilibrium.

7. I can design a solution while optimizing the various ways a material can undergo deformation.

Introductory Performance Task:

I can successfully design a system with limited consideration toward material characteristics, properties, composition, and behavior.
Future of Engineering in P-12

Standards or Learning Progressions

Evidence-based P-12 Curricula
Synergistic Activities
Coherence not Compliance

Standards for Preparation and Professional Development for Teachers of Engineering
Executive Summary

Website: https://www.p12engineering.org/