Engineering Design in STEM Education
Engineering Design Challenge Curriculum

Multi-functional Food Cooker Design Challenge

NCETE Core 4, Spring 2009, UGA

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K-12 Engineering Road Map

Engineering & Technology Main Courses Sequence

Grades K-5 (Kindergarten – Elementary School)

Knowledge Content

Integrated STEM Courses (3; one/ two years):

- Mathematics.
- Technology (1. **Intro to Science;** 2 **Intro to Engineering;** 3. **Intro to Technology)**

Design Process

- **Conceptual.**

Grades 6-8 (Middle School)

Knowledge Content

STEM-integrated Science & Technology Courses (6 Courses, one/semester):

- Engineering Technology (1. **Drafting**; 2. **3D Modeling** 3. **Power & Energy**; 4. **Construction Systems;** 5. **Manufacturing Systems.** 6. **Electrical Circuitry & Component Selection**).

Design Process

- **Engineering & Technology Experiment.**

Predictive Analysis:

- Formula-based calculations;
- Physical lab experiments.
- Digital simulation.

Grades 9-12 (High School)

Knowledge Content

STEM-integrated Engineering Courses (one/semester):

- Foundation (3 Courses 1. **Statics & Dynamics** 2. **Material Strength & Selection,** 3. **Heat Transfer & Thermodynamics**, or **Fluid Mechanics & Aerodynamics**).
- Pathways (3 Major Courses; one/semester).
- Design "Capstone" (2 Courses)

Design Process

- **"Analytic Reduction"** for Well-structured & analytic (9-11) for Main Courses
- Ill-structures and **"Systems Thinking"** (12) for "Capstone."

Dr. Mativo: **Animatronics** (interdisciplinary, integrative STEM); analysis & design
Other existing programs: **Project Lead The Way**, etc.

Integrated STEM Enrichment → Integrated Design

Dr. John M. Mativo

Animatronics

An Interdisciplinary & Integrative STEM Project for Teaching Engineering Analysis & Design

(Grades 7 – 12)

Designed by
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Teaching Engineering Design Process to Grades 9-12
(Under the Proposed Model)

With completion of Engineering Analysis Courses

1. Identify the Need
- ❑ Give Grades 9-12 students design assignment, which identifies a lack or shortage of something that is needed in the society.

2. Define a Problem
- ❑ Discuss with students issues relevant to the design assignment (scientific, engineering, technical, ethical, ecological, social, and economic)
- ❑ Review relevant engineering principles (concepts and formulas);
- ❑ Identify and specify criteria and constraints (governmental regulations, safety requirements, dimensions, weight, and cost, etc.) for the new design.

3. Gather Information
- ❑ Coach students on how to find existing solutions in the market or community (local, national, and international) through store or site visitations, to collect samples of existing products; and to conduct Internet and patent search;
- ❑ Coach students on how to analyze the strengths and weaknesses of existing products/systems, and tabulate the data;
- ❑ Coach students on how to generate ideas on possible improvement or innovation, within the criteria and constraints established in step 2;

4. Develop and Evaluate Alternative Solutions
- ❑ Coach student design teams on brainstorming for possible solutions incorporating various strengths of existing products/systems plus innovative features, using engineering notebook;
- ❑ Coach students on how to evaluate the ideas generated during brainstorming sessions in team meetings, and modify the ideas for presentation to instructor (with sketch and/or mock-ups);
- ❑ Evaluate students' initial design ideas and helps selecting the most appropriate design.

5. Analysis
- ❑ Coach students on mathematical predictions, and engineering experiment (if needed);
- ❑ Coach students on CAD modeling (using Inventor, SolidWorks, SolidEdge, etc.), and digital simulation (if possible);
- ❑ Coach students on writing a design proposal.

6. Decision
- ❑ Tram presentation to and evaluation by classmates and instructor (based on established criteria and constraints);
- ❑ Final modification of design in CAD, and digital simulation (if possible).

7. Test and Verify the Solution
- ❑ Coach students on building a prototype to test the final design solution;
- ❑ Coach students on making final changes (if needed);
- ❑ Coach students on making design specifications.

8. Communication
- ❑ Student teams' final presentation with oral demonstration, written design proposal, CAD 3D models, 2D drawings, and prototype.

Edward Locke's interpretation:

8-Step Engineering Design Process for Grades 9 -12 (NCETE)

Application of STEM

A variety of applicable knowledge content ("Mini Lessons"):

- Physics for Scientist and Engineers (Electricity and Heat Transfer/Thermadynamics). *6-Week Period.*
- Material Science. *3-Week Period*.
- Arts and Design. *2-Week Period*.
- Industrial Product Design. *4-Week Period*.
- Manufacturing and Engineering Economics. *2-Week Period*.

Open-ended design process:

- Requiring students to satisfy some pre-established criteria, which leads to the creation of numerous functional and balanced designs, without prescribing any set results.
- Students will be challenged to apply their engineering analytic knowledge, personal experiences, interests and talents to the process of creating an innovative team driven solution for a multi-functional, cost-effective, user-friendly and ecologically sustainable food cooking system.
- Team work environment.
- Student centered pedagogy (lecture plus tutoring/coaching)

Cognitively and socially mature Students:

- Senior-year (BS in K-12 Engineering and Technology Education
- Grade 12 (High school graduation year).

Models of Engineering Design Process

"Analytic Reduction" → "System Thinking"

Mini Lesson A (6 Wks):
Physics for Scientists and Engineers (Circuit Analysis and Heat Transfer)

Mini Lesson B (3 Wks):
Material Selection

"Analytic Reduction"
(Predictive Analysis)

Mini Lesson C (2 Wks):
Design Aesthetics and Graphic Presentation

Mini Lesson D (2 Wks):
Industrial Product Design

Mini Lesson E (2 Wks):
Manufacturing and Engineering Economics

"System Thinking"
(Multidisciplinary Application of Knowledge)

Assessment

Backward Design template:

- **Result-oriented** evaluation criteria (closed-ended engineering predictive analysis, plus open-ended design process and results).
- **Descriptive** (coaching, tutoring, critique) plus **evaluative** (multiple-choice testing, worked-out problems, write-ups).

Standard for Mini Lessons

Mini Lesson A (Physics for Scientist and Engineers and Heat Transfer/ Thermodynamics)

- *Electrical energy can be transformed into thermal energy;*
- *Design of a potentiometer;*
- *Ohm's Law.*

Mini Lesson B. Material Science

- *Properties and applications of different types of metal, plastics and ceramics will be studied;*
- *Locating suppliers of materials relevant to the design project.*

Mini Lesson C (Arts and Design)

- *Aesthetics reflect cultural values as well as personal preferences;*
- *Aesthetics can be represented by visual elements, such as three-dimensional forms, two-dimensional shapes, colors, lines, etc.;*
- *Aesthetics is an important factor in creativity.*

Standard for Mini Lessons

Mini Lesson D (Industrial Product Design)

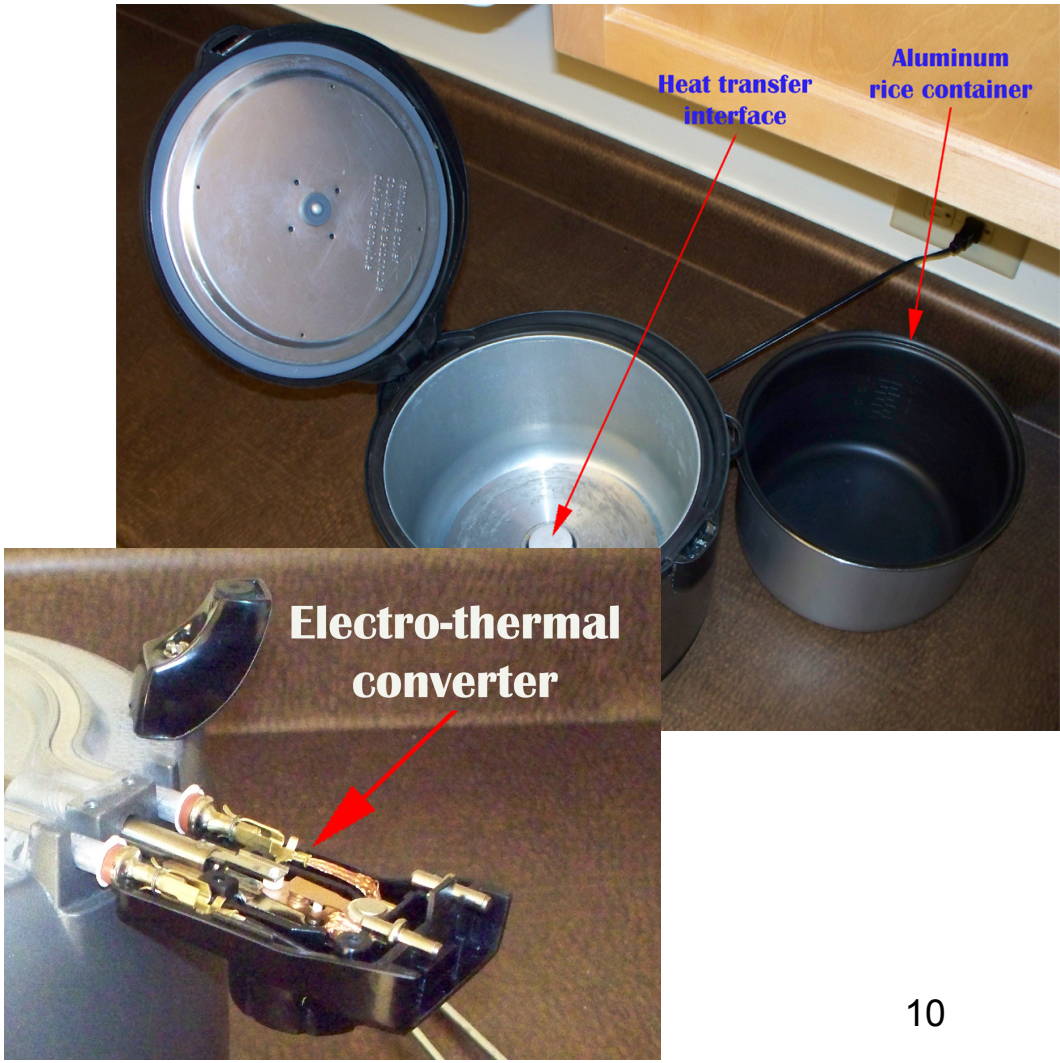
- *Engineering design (using the NCETE High School Engineering Design Process, as shown in Figure 3, as the basic process for product design);*
- *Ergonomics (user safety and convenience); and*
- *Aesthetics (two-dimensional graphics as well as three-dimensional shape of the product).*
- *Hybrid nature of product design.*
- *Serving legitimate social needs (profit, safety, affordability, etc.);*
- *Be ecologically sustainable (multiple functionality, recyclability, standardization, upgradability, etc.)*

Mini Lesson E. Manufacturing and Engineering Economics

- *Products should be designed in such a way that it will use the most effective manufacturing process and be as affordable as possible.*

Reverse Engineering

 Nostalgia Electrics Old Fashioned Hot Dog Roller Grill/Griddle $59.99 http://www.sears.com/shc/s/p_10153_12605_00897759000P?keyword=electric+griddle	 West Bend Breadmaker $145.99 http://www.sears.com/shc/s/p_10153_12605_00888155000P?keyword=waffle+maker	 Black & Decker Extra Large Electric Skillet with Glass Lid $ 36.99 http://www.kmart.com/shc/s/p_10151_10104_011W9726281100001P?vName=Appliances&cName=Small%20Kitchen%20Appliances&sName=Griddles%20&%20Grills&sid=K-on-Sx20k061224x0000002#descriptionAnchor
 Kenmore Water-Pumping Coffeemaker $10.99 http://www.sears.com/shc/s/p_10153_12605_05235180000P?keyword=coffee+maker	 National Presto PowerCrisp" microwave bacon cooker $18.99 http://www.sears.com/shc/s/p_10153_12605_00880731000P?keyword=egg+cooker	 Krups Egg Express Cooker $29.99 http://www.sears.com/shc/s/p_10153_12605_00848643000P?keyword=egg+cooker#desc
	 Aroma 5-Tier Rotating Food Dehydrator	 George Foreman's G5 Grill with 5 Interchangeable Plates



Design Challenge

- To design a **multi-functional** food cooking device with a **master electro-thermal converter** with variable temperature settings and **a variety of food cooking container attachment**, with a fully-functional working prototype and other professional design presentation materials.

Predictive Analysis

Product (Electro- Thermal Converter)	Wattage P [W] *	Current I [A]**	Resistance R [Ω] ***
Nesco 5 Quart Double Decker Food Steamer - 2 Trays, 60 Minute Timer			
Hamilton Beach 3-in-1 Slow Cooker			
Panasonic 10 Cup Rice Cooker / Steamer			
…			

Notes:
P can be found from Internet or packaging.
** Calculated (P = IV → V = Constant = 220 V; I = P/V)
*** Calculated (V = IR → R = V/I where V = Constant = 220 V)

Predictive Analysis

Product (Food Container)	Thickness x [in] *	Base Area A [in^2]**	Volume V [in^3]***	Temperature T [°C] ****
Nesco 5 Quart Double Decker Food Steamer - 2 Trays, 60 Minute Timer				
Hamilton Beach 3-in-1 Slow Cooker				
Panasonic 10 Cup Rice Cooker / Steamer				

Notes:
- * x is the thickness of the container (also designated as L).
- ** A is the area of the base of the container.
- *** Formulas for the volume varies (if the container's shape makes computation difficult, then water can be pulled into it and then into another container with regular shape such as a calibrated measurement cup, so as to obtain the volume).
- **** T (temperature) can be calculated using formulas such as

$$\wp = kA\left|\frac{dT}{dx}\right| = kA\left(\frac{T_h - T_c}{L}\right)$$

Design & Prototyping

- Master potentiometer and thermal transfer interface;
- Container attachments.

Connections to National Curriculum Standards

- Based on STEM for Grades 9-12 (pre-calculus math, physics, chemistry and technology education); → ITEA.
- Focus on system thinking and integration of interdisciplinary knowledge. Content.

Evaluation/ Assessment

Statistics analysis on:

- Quizzes, home works (writings and worked-out problems)
- Design results.

Preparing to Teach

Instructor will make a sample design (with lab experiment write-ups, Engineering Notebook, etc.), to be shown to students.

Opportunities for Extension

From **STEM-based engineering challenge** (Mini Lesson A: Physics with focus on electrical analysis and heat transfer); and B. Material Science) to

- **Technology** (Mini Lesson D. Industrial Product Design; and E. Manufacturing); and
- **Art and Design** (Mini Lesson C).

Resources

- Previous textbooks;
- Internet;
- Sample products;
- Electronics components;
- Plastic, metal materials;
- Physics lab
- CNC labs;
- Solftware (CAD such as Inventor; simulation such as Electronics Workbench

Another Engineering Design Challenge

Multi-Functional Food Processor

"Analytic Reduction" → "System Thinking"

Mini Lesson A (6 Wks): **Physics for Scientists and Engineers (Electricity and Mechanism)**

Mini Lesson B (3 Wks): **Material Selection**

"Analytic Reduction" (Predictive Analysis)

Food Processor = Motor + Blade/Container

Mini Lesson C (2 Wks): **Design Aesthetics and Graphic Presentation**

Mini Lesson D (2 Wks): **Industrial Product Design**

Mini Lesson E (2 Wks): **Manufacturing and Engineering Economics**

"System Thinking" (Multidisciplinary Application of Knowledge)

Questions