APPENDIX 1-A-3

Infusing Engineering Design into

K-12 Engineering and Technology Teacher Education Program

Sample Unit 3:

Well-structured Problem and Simple Engineering Design

“Analytic Reduction” Stage

“Combined Engineering and Technology Design Process”

K-12 Engineering & Technology Teacher Education Course:

ETES ? - Mechanism Design and Selection

(Pre-Calculus Version, proposed for UGA)

TECH (N 10 & 12) High School Engineering: Mechanism Design & Selection I & II (Proposed for CSULA)

(For proposed course description, refer to Appendices 1-D and 1-F)

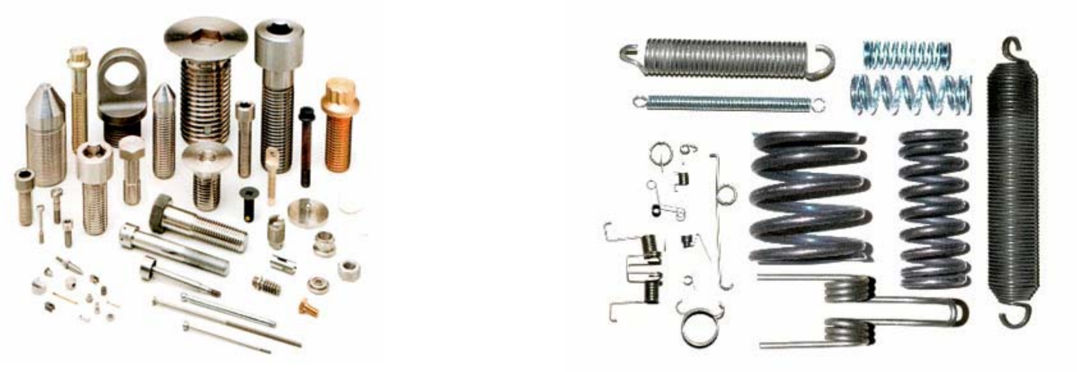
Eventual Clientele: High School Engineering & Technology (Grades 9 - 12)

Description of the sample unit (The engineering design projects):

Assignment (to be given at the start of the course): In this course, many mechanical components and devices, such as fasteners, springs, gears (spur, helical, bevel and worm), belt and chain drives, keys and couplings, clutches and brakes, shaft, screws (power and ball), bearings (plain surface, ball and roller) will be explored (see *Figure 1*). In addition basic principles of mechanical design, as well as fundamental principles of science, such as force, work, and power, stress and deformation, combined stress and failure, repeated loading, kinematic analysis of mechanisms, tolerance and interference, will be reviewed. As future K-12 engineering and technology teachers, students will

1. Well-structured but open-ended Design: Design a simple mechanical system with at least three sub-assemblies, using as many as the above mentioned mechanical devices or components. This device or system should be able to perform as many different functions as possible.

2. Curriculum development: Develop an instructional unit for teaching basic principles of mechanical design to K-12 students, which should be based on the above assigned mechanical system design. This should include: a. Plan of Instruction; b. Teacher’s Report; c. PowerPoint presentation; d. Scaled model; c. Handouts for K-12 students (learning materials, home work assignment, basic principles and formulas sheets, useful Internet addresses, and others).



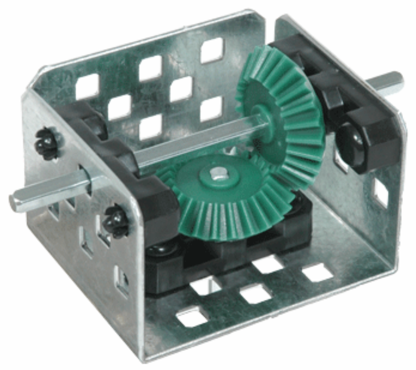
Fasteners

Springs

Figure 1 Examples of mechanical devices and components (Source: Google Image Search at http://images.google.com/)

Spur gears

Helical gears



Bevel gears

Worm gears

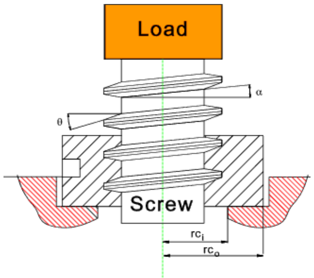
Belt and chain drives

Keys and couplings

Clutches and brakes

Figure 1 (Continued)

Shaft



Power Screw

Ball screw

Plain surface bearings

Ball bearings

Roller bearing

Figure 1 (Continued)

<u>Organization of design teams</u>: Students will work in groups of 4 - 5 members under instructor’s supervision. Group members will work together to frame the overall research and design strategy, to divide the research and tasks among the members and to coordinate the efforts of individual members into achievement of group objectives.

<u>Management of design teams</u>: At each stage of the design process, each team will have a Coordinator to coordinate the activities of the members; the role of Coordinator will rotate among the team members. The Coordinator will keep a work progress log.

<u>Supervision of design teams</u>: The instructor of the course will supervise the activities of each student design team and give advice when requested.

<u>Design process</u>: The following Combined Engineering and Technology Design Process will be used throughout the entire research and design process:

- ☐ Defining the problem and identify the need for a solution.

☐ Researching existing solutions in the market or community (local, national, and international) through visitation and/or internet search, analyzing their strengths and shortcomings for a possible better solution.

☐ Generating ideas through 3-4-5 brainstorming sessions for better solutions incorporating various strengths of existing products/systems plus innovative features.

☐ Identifying and specifying criteria and constraints for new design.

☐ Comparing and evaluating solution ideas generated during the brainstorming sessions against the established criteria and constraints.

☐ Selecting the most suitable approach to solution and developing a design proposal based on analysis of engineering design factors.

☐ Mathematical predictions and digital simulation if possible.

☐ Decision making and design specifications.

☐ Building a model or prototype.

☐ Testing and evaluating the design.

☐ Refining the design.

☐ Communicating results with cad 3d models and 2D drawings.

Introduction:

In conducting this design activity, students will learn to solve a fairly well-structured, simple but open-ended engineering design problem, using the principles and methodology of "Analytic Reduction."

"Analytic Reduction" concepts: The theory of "Analytic Reduction" is based on Newtonian sciences, which refers to "both a collection of established principles on the nature of the universe and the particular methods of investigation and verification by which those principles are established;" these methods are mostly "organized around the standard of proof through replication. Hypotheses become facts and theories become truths as researchers are able to demonstrate that predictable and repeatable results can be obtained" (p. 17). Newtonian sciences worked well for the studies of mechanical phenomena, which are to a large degree predictable, and supported a belief that the universe was a "grand machine" (Davis & Sumara, 2006, p. 24). Descartes held that non-human animals could be reductively explained as automata (see *Figure 2*). Reductionism can either mean (a) an approach to understanding the nature of complex things by reducing them to the interactions of their parts, or to simpler or more fundamental things or (b) a philosophical position that a complex system is nothing but the sum of its parts, and that an account of it can be reduced to accounts of individual constituents *(Wikipedia, 2008).* In this engineering design project, the "Analytic Reduction" model could be used to break the whole mechanical device or system into separate parts, analyze the functions of each part and solve the engineering design problem part by part.

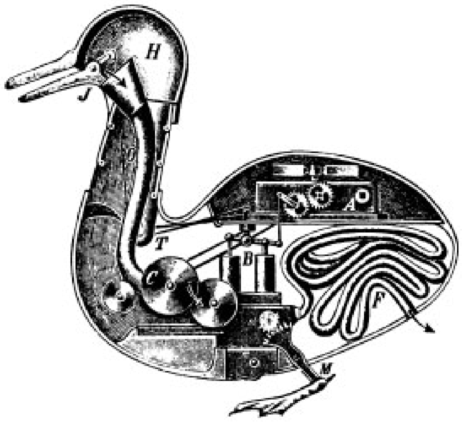


Figure 2 Descartes' reduction of non-human animals into parts of an automata (Wikipedia, 2008)

"Analytic Reduction" Activities: In this engineering design project, student teams are to first come up with an idea on what functions the mechanical system to be designed should perform. Next, the student teams should consult with the instructor on the types of mechanical devices and components would perform the intended functions. Next, during the course, student teams would design separate devices and sub-assemblies while learning the related topics; and finally, student teams would put the whole design together and give a presentation in the Finals week.

"Reverse Engineering" Activities: Student teams could pick up any recycled mechanical system (for example, old kitchen appliances), disassemble the system to learn how parts and components work. Before the disassembly starts, student team members should consult with the instructor on safety issues.

The main issues to be addressed:

For the mechanical system design: Using "Analytic Reduction" concepts to define the design problem, students are to answer the following questions:

- Overall analysis: What functions can various mechanical devices and components perform, both as individual pieces and as related ones, in terms of their separate intended usages, and the overall relations among them; and how can these relationships can be understood in order to design a simple mechanical system that can perform several functions?

- Particular design strategies: What are the engineering principles related to various mechanical devices and component that can be used to solve the above engineering design problems?

- Design resource or logistics: What are the available out-of-shelf devices and components and devices that can be incorporated into the new engineering designs? What are the devices and components that need to be designed from scratch? What are the available manufacturing technologies and materials to be used?

- Safety and ergonomics: What are the factors to be considered in order to ensure user safety and comfort when operating the newly designed appliances?

For curriculum development: Students are to apply the principles of "Analytic Reduction" to break down the instructional material into small units that can be covered in one class meeting at K-12 level, with appropriate integration of engineering design principles, concepts, formulas, exercise and review problems, and other necessary elements.

Students are to understand that the mechanical system design project deal with fairly well-structured, simple but open- problems. There are no single correct ways to solve the overall design problem; however, the solution of design problem for each separate component or sub-assembly should be based on the most appropriate and relevant application of mechanical design principles, concepts, and formulas. Practical solutions are those that are based on correct application of knowledge and skills learned from each topics covered in the course.

Learning Objectives:

The most important objectives of this design project include:

1. To learn how to correctly apply mechanical design principles, concepts, and formulas, so as to solve well-structured and simple engineering design problems, using "Analytic Reduction" concepts;

2. To learn the basics of "reverse engineering;"

3. To learn how to be creative but practical through rational analysis of overall design strategy generated during brainstorming sessions.

4. To learn how to search for available out-of-shelf devices and components through the Internet, and to integrate them with devices and components to be designed;

Design Constraints:

The mechanical system design project would have open-ended solutions, within the general requirements that the end product use at least three types of mechanical devices and components covered in the course, and at least three sub-assemblies. However, the following design constraints should apply:

1. The dimensions of the final assembled mechanical system should not exceed 10 in x 10 in x 10 in;

2. The weight of the final assembled mechanical system should not exceed 40 pounds;

3. The total price for purchasing out-of-shelf devices, components and materials should not exceed $300. Student design team members would share the cost.

Predictive Analysis:

All appropriate concepts and formulas should be used and recorded while designing separate devices and sub-assemblies of this mechanical system project.

Engineering design documentation:

The following documentations are required for both projects:

Engineering design progress log: The rotating Coordinator of each team will record the progress of each team member.

Engineering notebook: Throughout the entire design process, each team member will record all related activities with sketches, notes, calculations, attachment of CAD printouts, on engineering notebook, following the standards and conventions of its usage.

PowerPoint presentation: Each team will develop PowerPoint files and handouts for in-class presentations of the final design.

Reference

Davis, B., & Sumara, D. (2006). *Complexity & education inquiries into learning, teaching & research*. London: Lawrence Erlbaum associates, Publishers.

Wikipedia. (2008). *Reductionism.* From http://en.wikipedia.org/wiki/Scientific_reductionism

APPENDIX 1-A-4

Infusing Engineering Design into K-12 Engineering and Technology Teacher Education Program

Sample Unit 4:

Ill-structured Problem and Complex Engineering Design

“Systems Thinking” Stage of Holistic Design

“Combined Engineering and Technology Design Process”

K-12 Engineering & Technology Teacher Education Course:

ETES 5110B/7110B - Engineering Design II (Proposed for UGA)

TECH (N 19BC) - K-12 Engineering Design Senior Project II & III (Proposed for CSULA)

(For proposed course description, refer to Appendices D and F)

Eventual Clientele:

High School Engineering & Technology “Capstone” Course (Grades 9 - 12)

Description of the sample unit (The engineering design projects):

Assignment: In this course, two major Engineering Design Group Projects are assigned, for students taking the Mechanical Design, Manufacturing Systems, Electrical and Electronics Options in the proposed K-12 Engineering and Technology Teacher Education program:

1. Multifunctional Food Processor: This device should be able to perform the various related but different functions currently performed by various products in the market place, including but not limited to ham slice cutter, food chopper, food mixer, blender, salad shooter, juice maker, and others (see *Figure 1A and Figure 1B*).

Cuisinart Food Processor

KitchenAid K50 - 5KPM50 Food Mixer

Hamilton 990 Food Blender

Presto 02972 Pro Salad Shooter

Nesco Food & Meat Slicer

Waring Pro Juice Maker PJC44U

Figure 1A Examples of available food processors. (Source: Google Image Search at http://images.google.com/)

Weston Brand Heavy Duty Electric Meat Grinder

Monforts Nut and Kernel Crusher

Figure 1A (Continued).

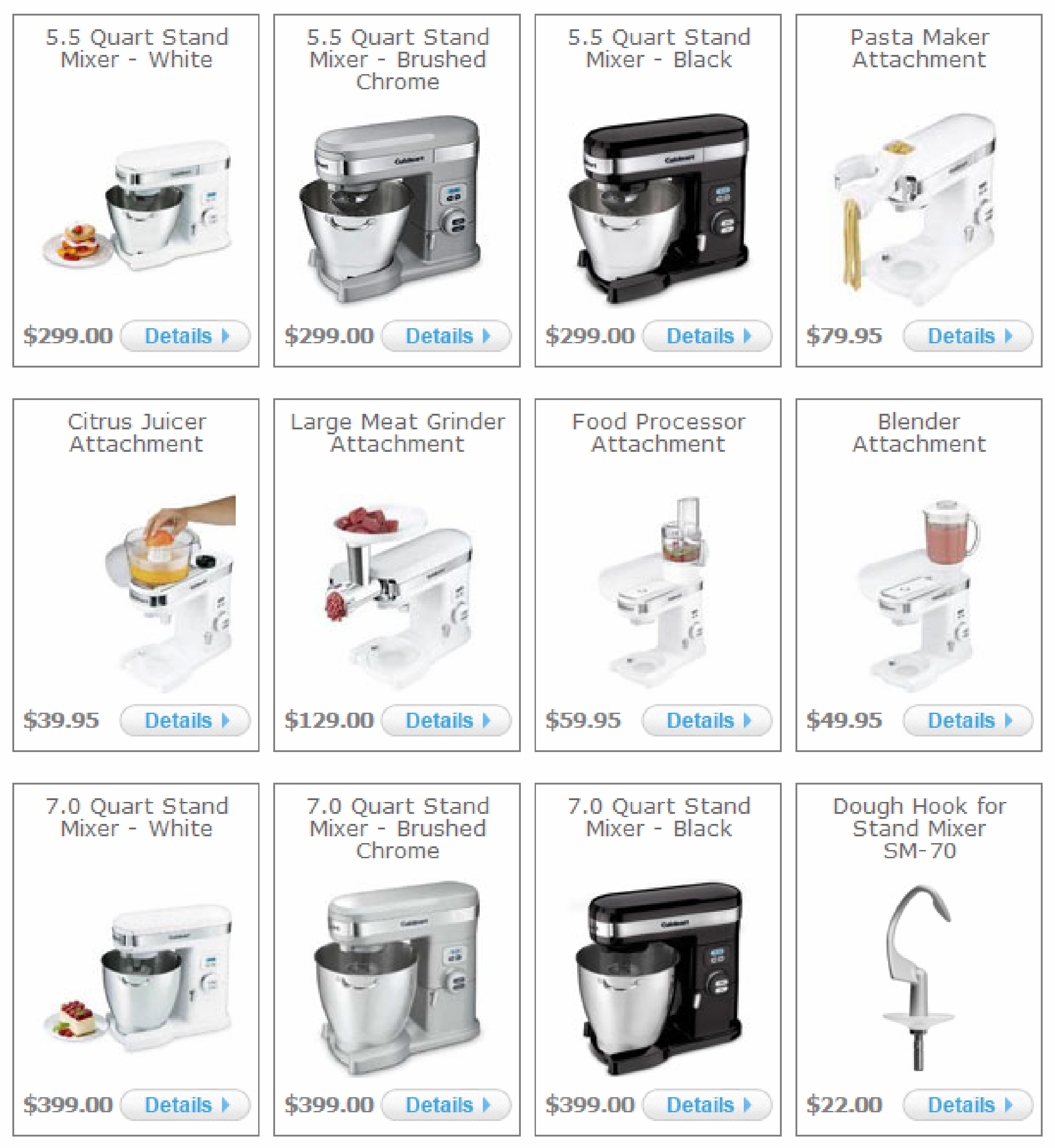


Figure 1B Cuisinart multi-functional food processor with diverse attachments (Source: http://www.cuisinartwebstore.com/product_list.asp?HDR=search&SEARCH=mixer)

SandiPak Bread Maker

Hamilton Beach 3-in-One Slow Cooker

SandiPak Toaster

Cuisinart Rice Cooker and Steamer CRC800U

SandiPak Detachable Deep Fryer

SandiPak Stone Grill & Hot Grill

SandiPak Sandwich Maker

SandiPak egg Cooker

SandiPak Pizza Maker

Figure 2 Examples of available food cookers. (Source: Google Image Search at http://images.google.com/)

2. Multifunctional Food Cooker: This device should be able to perform the various related but different functions currently performed by various products in the market place, including but not limited to rice cooker, vegetable steamer, toast maker, slow cooker, electrical pan, electrical wok, cookie maker, bread maker, and others (see *Figure 2*).

Organization of design teams: Students will work in groups of 8 - 10 members under instructor's supervision. Group members will work together to frame the overall research and design strategy, to divide the research and tasks among the members and to coordinate the efforts of individual members into achievement of group objectives.

Management of design teams: At each stage of the design process, each team will have a Coordinator to coordinate the activities of the members; the role of Coordinator will rotate among the team members. The Coordinator will keep a work progress log.

Supervision of design teams: The instructor of the course will supervise the activities of each student design team and give advice when requested.

Design process: The following Combined Engineering and Technology Design Process will be used throughout the entire research and design process:

- ☐ Defining the problem and identify the need for a solution.
- ☐ Researching existing solutions in the market or community (local, national, and international) through visitation and/or internet search, analyzing their strengths and shortcomings for a possible better solution.
- ☐ Generating ideas through 3-4-5 brainstorming sessions for better solutions incorporating various strengths of existing products/systems plus innovative features.
- ☐ Identifying and specifying criteria and constraints for new design.
- ☐ Comparing and evaluating solution ideas generated during the brainstorming sessions against the established criteria and constraints.
- ☐ Selecting the most suitable approach to solution and developing a design proposal based on analysis of engineering design factors.
- ☐ Mathematical predictions and digital simulation if possible.
- ☐ Decision making and design specifications.
- ☐ Building a model or prototype.

☐ Testing and evaluating the design.

☐ Refining the design.

☐ Communicating results with cad 3d models and 2D drawings.

Introduction:

In completing the two engineering design projects that constitute this unit, students will learn to solve ill-structured and complex engineering design problems, using the theory of "Systems Thinking."

"Systems Thinking" concepts: "Systems Thinking" is an approach to problem solving that views "problems" as parts of an overall system, rather than reacting to present outcomes or events and potentially contributing to further development of the undesired issue or problem. "Systems thinking" is a framework that is based on the belief that the component parts of a system can best be understood in the context of relationships with each other and with other systems, rather than in isolation. In contrast to Descartes' scientific reductionism, "Systems Thinking" proposes to view systems in a holistic manner, and constitutes an understanding of a system by examining the linkages and interactions between the elements that compose the entirety of the system. Basically, "Systems Thinking" is a way of helping a person to view systems from a broad perspective that includes seeing overall structures, patterns and cycles in systems, rather than seeing only specific events in the system (Wikipedia, 2008).

"Systems Thinking" Activities: In both engineering design projects, students are to first conduct market research and analysis of the design problem systematically and holistically, so as to formulate an overall design strategy, before actual design activities start. The principles of "Systems Thinking" should be used throughout all design activities, especially in the early stages of research and analysis. Market research should include two parts: (1) online research; (2) visitation to local stores that carry the relevant kitchen appliances, such as Sears, Wal-Mart, K-Mart, Target, and others.

The main issues to be addressed:

At technological level: Two major categories of food preparation appliances exist in today's marketplace: food processors and food cookers; a variety of these appliances are available, each performing one or a few closely related functions. For both categories of products, there exist similar as well as different components. For example, all food processors have a motor unit operating at various speeds and a specific food processing unit performing a particular function (such as a chopping blade and container). On the other hand, all food cookers have a heat-generating unit operating at various temperatures and a specific food cooking unit performing a particular function (such as a pizza mold or a rice container).

At philosophical level: Students are to apply the principles of “Systems Thinking” to analyze the available appliances, as well as the impact of their current design on a variety of social and ecological issues, including but not limited to affordability, benefits to users, consumption of natural resources, economics and profitability, recycling, etc..

Using “Systems Thinking” concepts to define the design problems at the above two levels, students are to answer the following questions:

- Systemic analysis: What are the similarities and differences among the various available appliances in each category, in terms of their features/components, and the overall relations among them; and how can these relationships can be understood in order to design a multi-functional food processor and a multi-functional food cooker?
- General design strategy: What are the engineering principles that can be used to solve the above engineering design problems?
- Design resource or logistics: What are the available out-of-shelf devices and components and devices that can be incorporated into the new engineering designs? What are the devices and components that need to be designed from scratch? What are the available manufacturing technologies and materials to be used?
- Societal and ecological benefits: What are the benefits of the new design to sustainable use of the Earth’s natural resources, to consumers, and to the potential manufacturers’ profitability? In other worlds, how to make the new products to be designed more affordable to consumers, with a decreased consumption of raw materials per unit, while allowing the cost of purchase to drop, and at the same time, increase the products’ market share?
- Safety and ergonomics: What are the factors to be considered in order to ensure user safety and comfort when operating the newly designed appliances?

Students are to understand that both projects deal with ill-structured and complex problems. There are no single correct ways to solve the design problems. There are no “best” designs either. Instead, there are different strategies that can be used to achieve the same design objectives. Practical solutions are those that satisfy various and sometimes conflicting criteria in a balanced manner.

Learning Objectives:

The most important objectives of this course include:

1. To learn how to solve ill-structured and complex engineering design problems, using "Systems Thinking" concepts;

2. To learn how to critically analyze and compare existing products and systems, and to find innovative engineering design solution that will incorporate beneficial features of existing products and systems with new features;

3. To learn how to be creative through well-tested mechanisms such as brainstorming sessions.

4. To learn how to integrate engineering analytic and predictive principles and skills from various previous coursework (such as statics and dynamics, strength of materials and material selection, CAD, mechanical design), so as to solve a real-world like and complex engineering design problem.

5. To learn how to integrate available out-of-shelf components with features and components to be designed;

6. To integrate all aspects of engineering design, from not only technical perspective, but also social, economic and ecological perspectives.

Design Constraints:

The two engineering design projects will have open-ended solutions, within the general requirements that the end products to be designed should be multi-functional. However, the following design constraints should apply:

1. The end products are intended for household (non-industrial) usage;

2. The dimensions of the main multi-functional products should not exceed 12 in x 12 in x 15 in; the overall dimensions of the main multi-functional products plus all attachments should not exceed 20 in x 20 in x 15 in;

3. The weight of the main multi-functional products should not exceed 20 pounds; the overall weight of the main multi-functional products plus all attachments should not exceed 40 pounds;

4. The projected retail price of the main multi-functional products plus one attachment used to perform one or a series of related functions should not exceed $200; the projected retail price of any additional attachment should not exceed $30.

Predictive Analysis:

For the 1st Engineering Design Group Project (Multifunctional Food Processor): The various speeds, torques and other perimeters of electric motors used in various existing food processors; the range of speeds, torques and other perimeters for an out-of-shelf variable speed motor unit to be used in the main multi-functional food processor unit; the dimensions, weight and other perimeters of various attachment.

For the 2nd Engineering Design Group Project (Multifunctional Food Cooker): The various thermal and electrical perimeters of electro-thermal mechanisms used in various existing food processors; the range of thermal and electrical perimeters for out-of-shelf electro-thermal devices to be used in the main multi-functional food cooker unit; the dimensions, weight and other perimeters of various attachment.

Engineering design documentation:

The following documentations are required for both projects:

Engineering design progress log: The rotating Coordinator of each team will record the progress of each team member.

Engineering notebook: Throughout the entire design process, each team member will record all related activities with sketches, notes, calculations, attachment of CAD printouts, on engineering notebook, following the standards and conventions of its usage.

PowerPoint presentation: Each team will develop PowerPoint files and handouts for in-class presentations of the final design.

Evaluation Criteria:

The final design solutions for both projects should be:

1. Creative and innovative: The design solutions should be substantially different to those available in the market-place;
2. Technologically feasible: The design solutions should lead to the most cost-effective manufacturing and assembly process;

3. Operationally viable: The design solutions should offer end users maximum safety and comfort;

4. Capable of accommodating emerging needs: The design solutions should be able to accommodate additional attachment to be designed in the future.

Reminder to students:

Students should be aware of the changes that have occurred in engineering design practice, which have been summarized by Wicklein and Thompson (2008), include:

- Change from focus on product quantity and affordability to focus on quality;
- Change from sequential "over-the-wall engineering" with "little or no interaction between the different parts of the design and manufacturing process" to concurrent engineering based on collaborative interaction among engineers from many different fields, and representatives from marketing, manufacturing, legal, distribution, packaging, and others;
- Change from company-centered R&D with no customer input to "user-centered-design process;"
- Change from mere concern for profit margins to "Green Design" or "Sustainable Design," with "an alternative philosophy in which the design engineer is much more aware of environmental stewardship, social responsibility and economic viability."

Reference

Wikipedia (2008). *Systems thinking*. From http://en.wikipedia.org/wiki/Systems_thinking

Wicklein, R. C., & Thompson, S. A. (2008). *Chapter 4: The unique aspects of engineering design*. From https://webct.uga.edu/SCRIPT/nceterw/scripts/serve_home