PLTW BE Science Framework

PLTW Course: Biotechnical Engineering (BE)

Science Strand being addressed: Strand 1: Nature of Science and Engineering
Science Sub-strand being addressed: Sub-strand 2: The Practice of Engineering

Science Standard being addressed: 9.1.2.2

Overview:

MN Science Standard and Benchmarks: 9.1.2.2, 9.1.2.2.1, 9.1.2.2.2

Standard 9.1.2.2: Engineering design is an analytical and creative process of devising a solution to meet a need or solve a specific problem.

Benchmark 9.1.2.2.1: Identify a problem and the associated constraints on possible design solutions.
For example: Constraints can include time, money, scientific knowledge and available technology.

Benchmark 9.1.2.2.2: Develop possible solutions to an engineering problem and evaluate them using conceptual, physical and mathematical models to determine the extent to which the solutions meet the design specifications.
For example: Develop a prototype to test the quality, efficiency and productivity of a product.

Correlation to AAAS Atlas (Benchmarks for Science Literacy):
3A/H1*, 3A/H2, 3A/H4**, 2B/H1*, 12EST1, 12EST1.1, 12EST1.2, 12EST1.3, 12EST1.4

- Technological problems and advances often create a demand for new scientific knowledge, and new technologies make it possible for scientists to extend their research in new ways or to undertake entirely new lines of research. The very availability of new technology itself often sparks scientific advance. 3A/H1*
- Mathematics, creativity, logic, and originality are all needed to improve technology. 3A/H2
- Engineers use knowledge of science and technology, together with strategies of design, to solve practical problems. Scientific knowledge provides a means of estimating what the behavior of things will be even before they are made. Moreover, science often suggests new kinds of behavior that had not even been imagined before, and so leads to new technologies. 3A/H4** (SFAA)

- Mathematical modeling aids in technological design by simulating how a proposed system might behave. 2B/H1*

Correlation to NSES (National Science Education Standards):
Abilities of technological design (12EST1)
- Identify a problem or design an opportunity (12EST1.1)
- Propose designs and choose between alternative solutions (12EST1.2)
- Implement a proposed solution (12EST1.3)
- Evaluate the solution and its consequences (12EST1.4)

Essential Understandings/Big Ideas:

- Engineering design is the creative process of solving problems using science and technology.
- There are several steps involved: the problem or need is clearly identified along with required constraints, possible solutions are proposed, each alternative design is evaluated using conceptual, physical and mathematical models to determine the extent to which the alternative solutions meet the design specifications, and finally, a proposed solution is selected for further development and testing.

Constraints limit or restrict a designed application and may prevent it from reaching its full potential. In engineering design, constraints must be identified and adhered to during the design process. Constraints are varied according to the particular problem, but common constraints include time, money, scientific knowledge and available technology. Most engineering design projects have a timeline within which they must complete their work and there are limited funds available for research, development, testing, and manufacture of the product. Sometimes the proposed solutions are breaking new ground with new scientific phenomena or concepts not yet fully understood, and often engineers are limited by technology and must create new technological tools to be able to go forward with their design.

When evaluating each alternative design, several different types of models can be used. Conceptual models describe the essential features and identify the principle processes that take place in the design. This can be communicated through a series of annotated sketches, a concept map, or a flow chart diagram, and should address all of the “what ifs” of the design.

Physical models are generally smaller or larger versions of the designed object. Often these models will be similar in geometry and shape, just on a different scale. The physical model may or may not be fully operational. Mathematical models are abstract descriptions of a system using mathematical concepts and can take many forms, such as statistical models, logical models, or mathematical equations. The intent is for the mathematical model to agree with the experimental data results and be able to predict future results consistently.

What should students know and be able to do [at a mastery level] related to these benchmarks?

Students should be able to:

- Identify a problem or design opportunity driving the need for a solution.
- Understand that all constraints of a certain problem must be clearly identified before developing possible solutions.
- Propose designs and choose between alternative solutions.
- Understand the role of models and simulations in the process of evaluating alternative designs.
- Evaluate the proposed solution against the needs and criteria it was designed to meet.

Misconceptions:

Student Misconceptions

- Ideas for new products come to engineers as "revelations" without any research into the process or products that currently exist.
- Cost is the only limiting factor in the design of a product.
- Physical models are the only reliable means to evaluate the effectiveness of a design

Teacher Resources:

Teacher Notes

There are several major design activities in units 3, 4 and 5 of the Biotechnical Engineering curriculum that address the concept of engineering design, constraints, and using models.

- **Activity 3.1.7 Designer Genes: Industrial Applications:** The students are asked to identify a problem and design a solution which will "improve the human condition" using fluorescent proteins and gene modification. Students communicate conceptual models and explain how their design will solve the problem.
- **Activity 4.1.1 Fermentation Instrumentation, Activity 4.1.2 Optimizing Yeast Fermentation, and Project 4.1.3 Fueled by Fungi:** These three interrelated activities are part of an overarching project that requires students to research fermentation, develop a method to test and measure rates of fermentation, optimize reaction rates, and build a car that is fueled by fermentation.
- **Problem 4.1.5 What's Eating You:** Student teams design an experiment to test the effectiveness of oil eating bacteria on oil that has spilled into the ocean by writing a design brief that explains the problem, identifies the solution expectations and the degree to which that solution will be realized, and lists any appropriate project constraints.
- **Activity 4.1.6 Bioengineering: Agriculture, Project 4.1.7 Aquaponics Systems, and Activity 4.1.8 Aquaponics Final Analysis:** This set of optional activities and projects allows students to research, design, build, and monitor their own Aquaponics System.

- **Activity 5.1.1 Biomedical Guidelines:** Students research a biomedical product failure case study and apply the *Product Development Lifecycle* to the case study, then communicate their findings to the class via PowerPoint.
- **Project 5.2.3 Material Properties of Joints:** Students design, construct a physical model, and evaluate a joint replacement.

It is most important that the students understand what the problem is first. It takes some collaboration and group thought to come to this. It is only then that realistic solutions can be considered. Students will also need some assistance to identify the project constraints. Teachers may want to develop a template or worksheet for students to brainstorm and record possible constraints, then follow this with a class discussion to ensure all students are working within the same set of limits and criteria.

Students generally have the most difficulty understanding the content of these projects rather than the design process and problem solving aspect. Teachers will often need to pre-teach the content using supplementary sources to enhance students' understanding. For example, in Activity 3.1.7, students will need a lesson on operons and the control of gene expression.

Project Lead the Way Example Design Process
There are many design processes that are used in the field. Project Lead The Way, Inc. has adopted this design process from Standards for Technological Literacy Standard 8, Benchmark H. This design process will be used for all courses.

Additional Instructional Resources:

Link to NASA video of the engineering design process:
http://nasa.ibiblio.org/video/NASASciFiles/NASASF-TheRadicalRide/qt/NASASF-EngineeringDesignProcess.mov.

Image Source:
Project Lead the Way, Inc. (2011). Intro to engineering design curriculum 2011-2012:. Clifton Park, NY: Project Lead the Way, Inc.

The design process includes:

1. Define a Problem
   - Identify a problem that exists.
   - Determine the root cause.
   - Gather information.

2. Brainstorm
   - Present ideas in group.
   - Generate and record ideas.
   - Seek quantity not quality.
   - Keep the mind alert through rapidly paced sessions.

3. Research and Generate Ideas
   - Analyze the reasons for the need, want, or problem.
   - Investigate who or what it is that is affected, and consider the need, want, or problem from their perspective.
   - Research any existing solutions, and identify why they are not adequate or appropriate.
   - Listen to clients to solve problems that they have discovered.
   - Perform market research to determine if a want or need exists and warrants the development of a design solution.

4. Identify Criteria and Specify Constraints
   - Identify the end user if the client is not.
   - Redefine the problem to the agreement of both client and engineer.
   - Identify what the solution must do, and the degree to which it will be pursued.
   - Identify the limitations within which the engineer must perform his/her duties.
   - Compile the information into a design brief.

5. Explore Possibilities
   - Initiate further development of brainstorming ideas with constraints and tradeoffs considered.
   - Explore alternative ideas based on further knowledge and technologies.

6. Select an Approach
   - Create a decision-matrix to compare the attributes of the various ideas and analyze the trade-offs associated with each one.
   - Verify alignment between the idea selected and the criteria and constraints.

7. Develop a Design Proposal
   - Develop detailed and annotated sketches.

- Determine the type(s) of material from which the solution will be constructed.
- Make computer models.
- Create technical drawings from the computer model(s).

8. Make a Model or Prototype
   - Make study models (scaled models or mock-ups).
   - Fabricate a functional prototype.

9. Test and Evaluate the Design using Specifications
   - Test the prototype under controlled conditions.
   - Test the prototype under actual conditions.
   - Record the results.
   - Evaluate results to determine if problems exist and further work is needed.

10. Refine the Design
    - Reassess the validity of the design criteria and make adjustments to the design brief, if necessary.
    - Work through the design process until the solution satisfies the design criteria.
    - Update the documentation of the final solution.

11. Create or Make Solution
    - Determine Custom/Mass Production.
    - Consider packaging.

12. Communicate Processes and Results
    - Present oral presentations with visual aids (computer generated slide show, models, prototype).
    - Develop written reports with appropriate graphic documentation (charts, graphs, technical drawings, renderings, etc.).
    - Market the Product.
    - Distribute.

Source:
Project Lead the Way, Inc. (2011). Intro to engineering design curriculum 2011-2012: Lesson 1.1. Clifton Park, NY: Project Lead the Way, Inc.

New Vocabulary

- *conceptual model* - A theoretical model that describes the essential features and identifies the principle processes of the design.
- *constraints* - limitations to a project or procedure. These may be based on physical means or ethical means.
- *design solution* - Translation of a concept into a satisfactory, producible, salable form.

- *engineering* - a) The profession of or work performed by an engineer. b) The knowledge of the mathematical and natural sciences (biological and physical) gained by study, experience, and practice that are applied with judgment and creativity to develop ways to utilizes the materials and forces of nature for the benefit of humankind.
- mathematical model - A model based on mathematical principles.
- physical model - A concrete and usually smaller or larger versions of the designed object or product.

Vignettes:

Vignette #1

The class is building a device that will measure the efficiency of sugar fermentation by yeast. In this vignette the teacher is asking the students to verbally explain their design process. This is a way that a teacher can guide students through the thought process and model the analysis questions they should be asking themselves throughout the process.

Teacher: Show me your design solution for how to measure the rate of fermentation.

Student: We decided to try a new method. We were having trouble because the gas leaked out, so our results looked wrong.

Teacher: What did you try?

Student: Since we are limited to what materials are available, at first we tried it without the hose. But, then we connected it all together with this hose here (shows and points to a specific part).

Teacher: How does this improve your design?

Students: This way we don't have any leaks, and we can get better results to measure how fast the yeast make carbon dioxide.

Vignette #2

Once again, this is an illustration of how a teacher can check the understanding of the engineering design process by asking the student to verbalize how they can to a possible solution.

Teacher: O.K., so what is your design idea for the green fluorescent protein?

Student: We were thinking of making sunscreen that glows green under UV light!

Teacher: What is the problem or need that this product would solve?

Student: Well, we know it is hard for people to be able to tell whether or not they have completely covered their skin when applying sunscreen. So, the problem is that with regular sunscreen, it is hard to tell whether you have completely covered your body or not. We thought that having an indicator that shows where you have applied enough sunscreen might be a good idea.

Teacher: How would this work? What is your conceptual model?

Student: We would genetically engineer bacteria to produce the green fluorescent protein in large quantities in a bioreactor, then purify the protein and add it to the sunscreen in a stable form. When people apply the sunscreen, they would use the UV light that would come with the product and wave it over their skin to see if they have applied the product evenly. The green color would only show under the UV light, but not in regular sunlight. This could even be a way for people to tell if their sunscreen has rubbed off after swimming!

Teacher: Great! Continue to develop your model and identify the constraints for this product.

Assessments:

Assessments Methods

Assessments will be specific the to particular project or design activity, but should include either a detailed written report and/or class presentation which outlines students' design process.

3.1.7 Assessment

- Students communicate conceptual models and explain how their design will solve the problem using a PowerPoint presentation. Students will reflect on the quality of their models and evaluate the models of other students using a provided rubric (see rubric 3.1.7 in BE curriculum).

4.1.1-4.1.3 Assessment

- Students write an engineering report that addresses the possibilities for using the products of fermentation as an alternative energy source. The report should include an explanation of the optimization of the fermentation reaction, design sketches, rationale for the final design, and analysis of the results (see rubric 4.1.3 in BE curriculum).
- Relevant conclusion questions 4.1.1
    - What are some limitations in using end product analysis when measuring biological processes?

4.1.5 Assessment

- Student teams design an experiment to test the effectiveness of oil eating bacteria on oil that has spilled into the ocean by writing a design brief that explains the problem, identifies the solution expectations and the degree to which that solution will be realized, and lists any appropriate project constraints.

4.1.6-4.1.8 Assessment

- Student teams research, design, build, and monitor their own Aquaponics System. They must consider several designs and identify material and cost constraints, then chose the best design to produce. After monitoring and documenting their system for several weeks, they create a visual presentation to communicate their design solutions to the class (see rubrics).
- Relevant conclusion questions 4.1.6
    - What equipment do I have at my disposal?
    - Which plants and animals can I use in my system?
- Relevant conclusion questions 4.1.7
    - How will you determine if your project has been successful? Which criteria will you use to judge success?

5.1.1 Assessment

- Student teams, access the Internet and search for three product failure case studies in the biomedical field. Read each case study and, as a group, select a case of interest. The teams then apply *Product Development Lifecycle* to the case study they selected, and answer the conclusion questions as a means of evaluating the case study. The student teams create a PowerPoint presentation as a way of summarizing the conclusion questions. Include pictures or diagrams of the facilities used to manufacture the product from the case study. The PowerPoint presentation will be evaluated according to the activity 5.1.1 evaluation form (Found in the BE curriculum)
- Relevant conclusion questions 5.1.1
    - What was the need, at the time, for the product?
    - What alternate solution, design, or improvement was proposed for the product?
    - What new processes developed as a result of the product dilemmas?
    - What different prototypes were developed for the product?
    - What are some current problems with the product? How have these problems impacted society?
    - What documentation exists for the testing results of the product?
    - What are some quality control procedures used in product testing?
    - Is your product still in use today? Has it been replaced? Has it been improved?
    - What are the technological challenges of improving your product design and function?
    - What regulations, guidelines, or practices would ensure higher product safety and function for your product?
    - What are the governmental regulations associated with your selected case?
    - What are the manufacturing issues associated with your selected case?
    - What are the safety issues associated with your selected product or case?
    - Did the product fail?
        - If yes, why?
        - What improvements could have been made to eliminate the product failure?
        - How could those changes have been cost effective?
        - How could the improvements have allowed for product reliability and/or re-usability?

- Was the product failure a liability for the engineer or the company? Why?

5.2.3 Assessment

- Students design, construct a physical model, test and evaluate a joint replacement and write a technical report that documents the following: ROM, sketches, 3D model, materials properties and justification for chosen materials, and test results.

Differentiation:

Gifted and Talented:
Asking students to make a list of "what would you try next" and even allowing those students to make a new modification to their design

Special Education:
Allowing students to dictate their ideas for those who have trouble writing.
Assign intentional groups that will pair students that have difficulty with reading with other students that will read and do research.

English Language Learners
Much of the engineering vocabulary can be problematic even for students who speak fluent English. It is important that all students get in a habit of looking up unfamiliar words and ask for help. If all students are doing this it fosters a culture of learning and collaboration that encourages students to work together and understand complicated concepts.

Deliberate groups of students that speak the same language at different levels can help students that are less comfortable with new vocabulary.

Parents and Administration:

Administrative/Peer Classroom Observation:

Students Are:	**Teachers Are:**
Searching the web	Guiding web searches
building	helping to interpret results
measuring results	providing tools
discussing possible solutions	encouraging safety
identifying constraints	asking leading questions

evaluating models and protoypes	

Professional Learning Communities:

Professional Learning Communities may find it useful to discuss the following questions:

- What are some current, relevant engineering design issues we can use in the classroom to help students with the steps of identifying the problem and constraints?
- How can we help students to understand the steps of the design process?
- What resources will students need to make several models/prototypes and to test them?

The following resources may provide an additional opportunity for reflection and growth on these topics:

The Engineering Design Process http://www.sciencebuddies.org/engineering-design-process/engineering-design-process-steps.shtml.

Learning to Solve 'Design Problems' in Engineering Education http://www.sefi.be/wp-content/abstracts/1204.pdf.

Parent Resources:

Parents can encourage participation is a variety of activities and/or get involved themselves.

Allowing students to solve problems in the house and/or build things is a wonderful way to encourage engineering skills. The traditional tree house project provides for many of these opportunities.

References:

American Association for the Advancement of Science (1993): Benchmarks for Science Literacy. New York: Oxford University Press.

Minnesota Department of Education (2009): Minnesota Academic Standards: Science K-12, 2009 version. Retrieved from: http://education.state.mn.us/mdeprod/idcplg?IdcService=GET_FILE&dDocName=013906&RevisionSelectionMethod=latestReleased&Rendition=primary.

National Research Council (1996): National Science Education Standards. Washington, D.C.: National Academy Press.

Project Lead the Way, Inc. (2011). Biotechnical engineering curriculum 2011-2012: Clifton Park, NY: Project Lead the Way, Inc.

SciMathMN (2011): Framework 9.1.2.2: Practice of engineering. Retrieved from http://www.scimathmn.org/stemtc/frameworks/9122-practice-engineering.