Standards Guide to the STEM PBL (Problem Based Learning) Multimedia Challenges for the National Science, Mathematics and Technological Literacy Standards

Contents

Part 1. Overview

• *About STEM PBL*

The STEM (Science, Technology, Engineering and Mathematics) PBL (Problem Based Learning) Project (DUE #0903051) is funded by the Advanced Technological Education (ATE) program of the National Science Foundation (NSF) and directed by the New England Board of Higher Education (NEBHE). The project is developing problem-based learning (PBL) instructional resources and providing professional development activities in STEM subjects with a focus on sustainable technologies.

• *Using this Standards Guide*

This Guide includes the high-school level standards in the following documents:

- National Council of Teachers of Mathematics (NCTM) Standards
- National Science Education Standards (NSES)
- International Technology and Engineering Educators Association (ITEEA) Standards for Technological Literacy

The **Standards At-A-Glance** table lists the standards and identifies which Challenges address each standard. The symbols below are used in the At-A-Glance tables to indicate standards addressed by each Challenge:

Symbol	Applies to	Explanation
X	All Standards	Indicates that the standard is addressed in the specified Challenge.
G	NCTM Standards	**Mathematics standards addressed generally**. Eleven high-school-level NCTM expectations (about 11% of the total) are listed as "generally addressed" by each of the six Challenges. These broad goals (e.g., "compute fluently and make reasonable estimates") are not essential in most of the STEM PBL Challenges, but can be emphasized without difficulty in any of them.
+	NSES Standards	**Additional science standards**. In some cases, a particular Challenge is an opportune place to address a particular NSES standard, even though the Challenge could be completed satisfactorily without addressing the standard. An example is NSES standard C/6, "Behavior of Organisms" in the FloDesign Challenge. The potential damage to bird populations is identified as an issue in this scenario, although in the sample solution it is not addressed. Cases such as these are indicated with a "+" in Part 2 (**Standards At-A-Glance**) and are listed at the end of the science standards for each Challenge in Part 3 (**Standards addressed in the STEM PBL Challenges**).

Differentiation is made between standards addressed via the **context of the problem** (e.g., the "Life Science" standard is addressed in the Cranberry Challenge because students will be required to learn about the interdependence of organisms before developing a solution) and those addressed in the **discussion and solution**. Since mathematics per se isn't the context of any of the six challenges, all NCTM standards addressed in these challenges are addressed during the discussion and solution phases.

• About the NTCM, NSES and ITEEA Standards

Note on Terminology

For the purposes of analyzing these standards, the NCTM's "expectations" are roughly equivalent to ITEEA "benchmarks" and the "fundamental abilities and concepts" in the NSES.

National Council of Teachers of Mathematics (NCTM) Standards

The 10 math standards are divided among two larger categories: content standards and process standards. Content standards are somewhat grade-specific (e.g., there's more Geometry than Algebra in Kindergarten), while process standards (e.g., Problem-Solving) cut across the content. Each standard is broken down into what the NCTM calls "expectations." Expectations are pretty specific (e.g., "use vertex-edge graphs to model and solve problems"). There are a total of 104 high-school expectations. As is the case with the ITEEA standards, a PBL unit only addresses a NCTM standard if it directly relates to one (or more) of the expectations of that standard.

Suppose students use a tape measure, a protractor, and masking tape to lay out a full-scale floor plan of the submarine space they need to light in the RSL Challenge. If we review the NCTM standards hierarchy at the third level, a pretty good candidate appears: "Apply appropriate techniques, tools, and formulas to determine measurements." But the expectations list makes it clear that linear and angular measurement, per se, is not included in the standard:

- analyze precision, accuracy, and approximate error in measurement situations
- understand and use formulas for the area, surface area, and volume of geometric figures, including cones…
- apply informal concepts of successive approximation, upper and lower bounds, and limit in measurement…
- use unit analysis to check measurement computations.

So despite the fact that the students are "doing math" in laying out the floor plan, it's a level of math which they were expected to have attained (per the NCTM standards) before high school. Thus, the activity would not address the "apply appropriate techniques, tools, and formulas to determine measurements" expectation. (As it happens, this expectation is addressed elsewhere in the RSL Challenge.)

National Science Education Standards (NSES)

There are eight categories of national science standards: Unifying concepts and processes in science; Science as inquiry; Physical science; Life science; Earth and space science; Science and technology; Science in personal and social perspectives; and History and nature of science.

The first category—Unifying concepts—has five K-12 standards. The other seven include specific standards for grades 9-12; there are a total of 34 high-school standards.

The NSES document includes a number of "fundamental abilities and concepts that underlie" each high-school standard. Although these are all necessary to a complete acquisition of the standard, in each case, the list is explicitly incomplete. This means that a PBL Challenge may address a 9-12 NSES standard even if it doesn't relate to one of the fundamentals. For this standard analysis, however, a Challenge is considered to have addressed a standard only if one or more of the "fundamental abilities and concepts" listed beneath that standard.

International Technology & Engineering Educators Association (ITEEA) Standards

The Standards for Technological Literacy is a grouping of twenty standards among five broad categories: the Nature of Technology; Technology and Society; Design; Abilities for a Technological World; and the Designed World.

Each standard is divided into benchmarks at four grade ranges (K-2, 3-5, 6-8, 9-12). There are a total of 102 high-school benchmarks. Fifteen are abilities (e.g., "Design forecasting techniques to evaluate the results of altering natural systems"); the others are concepts (e.g., "The rate of technological development and diffusion is increasing rapidly").

The benchmarks appear to be completely inclusive of the standard at the specified grade range. In other words, students meeting the 10 high-school benchmarks of standard 2 (The Core Concepts of Technology) have met the standard itself. This means that a PBL Challenge address a high-school ITEEA standard only if it addresses one (or more) of the benchmarks.

Part 2. Standards At-A-Glance

(X = standard addressed in Challenge; G = standard generally addressed in PBL/STEM Chal-

National Council of Teachers of Mathematics (NCTM) Standards for Grades 9-12	FloDesign		Cranberry		RSL		TTF		SPG		J&J	
	context of the problem	discus-sion/ solution	context of the problem	discus-sion/ solution	context of the problem	discus-sion/ solution	context of the problem	discus-sion/ solution	context of the problem	discus-sion/ solution	context of the problem	discus-sion/ solution
Content Standards												
Number and Operations		**G**		**G**		**G**		**G**		**G**		**G**
Understand numbers, ways of representing numbers, relationships among numbers, and number systems		G		G		G		G		G		G
Understand meanings of operations and how they relate to one another		G		G		G		G		G		G
Compute fluently and make reasonable estimates		G		G		G		G		G		G
Algebra		**X**		**X**		**X**		**X**		**X**		**X**
Understand patterns, relations, and functions				X		X				X		X
Represent and analyze mathematical situations and structures using algebraic symbols		X		X		X		X		X		X
Use mathematical models to represent and understand quantitative relationships		X		X		X		X		X		X
Analyze change in various contexts												
Geometry		**G**		**X**		**G**		**X**		**X**		
Analyze … and develop mathematical arguments about geometric relationships										X		
… describe spatial relationships using coordinate geometry and other representational systems												
Apply transformations and use symmetry to analyze mathematical situations												
Use visualization, spatial reasoning, and geometric modeling to solve problems		G		X		G		X		X		
Measurement										**X**		**X**
Understand measurable attributes of objects and the units, systems, and processes of measurement		X				X		X		X		X
Apply appropriate techniques, tools, and formulas to determine measurements		X				X				X		X
Data Analysis and Probability		**X**				**X**						X
Formulate questions … and collect, organize, and display relevant data to answer them		X										X
Select and use appropriate statistical methods to analyze data		X										X
Develop and evaluate inferences and predictions that are based on data		X				X						X
Understand and apply basic concepts of probability												X
Process Standards												
Problem Solving		**X**		**X**		**X**		**G**		**X**		**X**
Build new mathematical knowledge through problem solving												
Solve problems that arise in mathematics and in other contexts		X		X		X				X		X
Apply and adapt a variety of appropriate strategies to solve problems		X		X		X				X		X
Monitor and reflect on the process of mathematical problem solving		G		G		G		G		G		G
Reasoning and Proof		**X**				**X**						
Recognize reasoning and proof as fundamental aspects of mathematics												
Make and investigate mathematical conjectures		X				X						
Develop and evaluate mathematical arguments and proofs												
Select and use various types of reasoning and methods of proof												
Communication		**X**		**X**		**X**		**X**		**X**		**X**
Organize and consolidate their mathematical thinking through communication		X		X		X		X		X		X
Communicate their mathematical thinking coherently and clearly to peers, teachers, and others		X		X		X		X		X		X
Analyze and evaluate the mathematical thinking and strategies of others		G		G		G		G		G		G
Use the language of mathematics to express mathematical ideas precisely		G		G		G		G		G		G
Connections		**G**		**G**		**G**		**G**		**G**		**G**
Recognize and use connections among mathematical ideas												
Understand how mathematical ideas interconnect and build on one another to produce a coherent whole												
Recognize and apply mathematics in contexts outside of mathematics		G		G		G		G		G		G
Representation		**X**		**X**				**X**		**X**		**X**
Create and use representations to organize, record, and communicate mathematical ideas								X		X		X
Select, apply, and translate among mathematical representations to solve problems												
Use representations to model and interpret physical, social, and mathematical phenomena		X		X				X		X		

Standards At-A-Glance, continued (X = standard addressed in Challenge; + = additional standard (see text))

National Science Education Standards (NSES) for Grades 9-12	FloDesign		Cranberry		RSL		TTF		SPG		J&J	
	context of the problem	discus-sion/ solution	context of the problem	discus-sion/ solution	context of the problem	discus-sion/ solution	context of the problem	discus-sion/ solution	context of the problem	discus-sion/ solution	context of the problem	discus-sion/ solution
Unifying concepts and processes in science												
Systems, order, and organization			**X**				**X**					
Evidence, models, and explanation												
Change, constancy, and measurement					**X**							
Evolution and equilibrium												
Form and function	**X**		**X**						**X**		**X**	
A. Science as Inquiry		**X**		**X**	**X**	**X**		**X**			**X**	**X**
A/1 Abilities necessary to do scientific inquiry		X		X	X	X		X			X	X
A/2 Understanding about scientific inquiry					X	X		X			X	X
B. Physical Science	**X**	**X**	**X**		**X**	**X**	**X**		**X**	**X**		
B/1 Structure of atoms												
B/2 Structure and properties of matter	+						X				X	
B/3 Chemical reactions			X								+	
B/4 Motions and forces	X	X	X						X	X		
B/5 Conservation of energy and increase in disorder									X	X		
B/6 Interactions of energy and matter					X				X	X		
C. Life Science			**X**	**X**	**X**				**X**	**X**	+	
C/1 The cell												
C/2 Molecular basis of heredity												
C/3 Biological evolution												
C/4 Interdependence of organisms			X						+			
C/5 Matter, energy, and organization in living systems									X			
C/6 Behavior of organisms	+				X				X			
D. Earth and space science												
D/1 Energy in the earth system												
D/2 Geochemical cycles												
D/3 Origin and evolution of the earth system												
D/4 Origin and evolution of the universe												
E. Science and Technology	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
E/1 Abilities of technological design	X	X	X	X	X		X	X	X	X	X	X
E/2 Understanding about science and technology	+		+								+	
F. Science in Personal and Social Perspective	**X**		**X**		**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
F/1 Personal and community health			X		X		X	X	X		X	X
F/2 Population growth							X		X			
F/3 Natural resources	X						X		X	X	X	
F/4 Environmental quality	X		X		X	X	X	X	X		X	
F/5 Natural and human-induced hazards	X		+		X		X	X	X		X	
F/6 Science and technology in local, national, and global challenges	+		X					X		X		X
G. History and Nature of Science											**X**	**X**
G/1 Science as a human endeavor							+				X	X
G/2 Nature of scientific knowledge												
G/3 Historical perspectives			+		+							

Standards At-A-Glance, continued (X = standard addressed in Challenge)

International Technology and Engineering Educators Association (ITEAA) Standards for Technological Literacy for Grades 9-12	**FloDesign**		**Cranberry**		**RSL**		**TTF**		**SPG**		**J&J**	
	context of the problem	discus-sion/ solution	context of the problem	discus-sion/ solution	context of the problem	discus-sion/ solution	context of the problem	discus-sion/ solution	context of the problem	discus-sion/ solution	context of the problem	discus-sion/ solution
The Nature of Technology	**X**		**X**		**X**				**X**		**X**	
1. Characteristics and scope of technology											X	
2. Core concepts of technology	X				X				X		X	
3. Relationships among technologies and the connections between technology and other fields…			X								X	
Technology and Society	**X**	**X**	**X**		**X**		**X**	**X**	**X**	**X**	**X**	**X**
4. Cultural, social, economic, and political effects of technology			X								X	X
5. Effects of technology on the environment	X	X	X		X		X	X	X	X	X	X
6. Role of society in the development and use of technology			X				X				X	
7. Influence of technology on history												
Design	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
8. Attributes of design	X	X	X	X	X	X	X	X	X	X	X	X
9. Engineering design	X	X			X	X			X	X	X	X
10. Role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving	X	X	X	X	X	X	X	X	X	X	X	X
Abilities for a Technological World	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
11. Apply the design process	X	X	X	X	X	X	X	X	X	X	X	X
12. Use and maintain technological products and systems							X	X	X	X	X	X
13. Assess the impact of products and systems	X	X					X	X	X	X	X	X
The Designed World	**X**	**X**	**X**	**X**	**X**		**X**	**X**	**X**	**X**	**X**	
14. Medical technologies												
15. Agricultural and related biotechnologies			X	X			X	X				
16. Energy and power technologies	X	X							X	X		
17. Information and communication technologies												
18. Transportation technologies					X							
19. Manufacturing technologies											X	
20. Construction technologies	X		X				X					

Standards addressed in the *FloDesign* Challenge

The following subset of the math, science, and technology standards are addressed by this Challenge. This is not a complete listing of all standards.

NCTM/Mathematics

The mathematics content standard most directly addressed in this Challenge is *Data Analysis and Probability*.

Content Standards

Algebra

Developing a solution to the FloDesign Challenge will require students to address these expectations from the *Algebra* standard:

Represent and analyze mathematical situations and structures using algebraic symbols

- use symbolic algebra to represent and explain mathematical relationships

Use mathematical models to represent and understand quantitative relationships

- identify essential quantitative relationships in a situation and determine the class or classes of functions that might model the relationships
- draw reasonable conclusions about a situation being modeled.
- approximate and interpret rates of change from graphical and numerical data.

Measurement

Design considerations, especially gear reduction and turbine shape relate to these *Measurement* expectations:

Understand measurable attributes of objects and the units, systems, and processes of measurement

- make decisions about units and scales that are appropriate for problem situations involving measurement.

Apply appropriate techniques, tools, and formulas to determine measurements

- understand and use formulas for the area, surface area, and volume of geometric figures, including cones, spheres, and cylinders

Data Analysis and Probability

Developing a solution to the FloDesign Challenge will require students to address these *Data Analysis* expectations:

Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them

- understand the differences among various kinds of studies and which types of inferences can legitimately be drawn from each
- compute basic statistics and understand the distinction between a statistic and a parameter.

The FloDesign study to identify turbine safety (from the Challenge's problem statement) relates to this *Data Analysis* expectation:

Develop and evaluate inferences and predictions that are based on data

- understand how sample statistics reflect the values of population parameters and use sampling distributions as the basis for informal inference

Process Standards

Designing a solution to this Challenge will require students to address these expectations from the *Process Standards*:

Problem Solving

- solve problems that arise in mathematics and in other contexts
- apply and adapt a variety of appropriate strategies to solve problems

Reasoning and Proof

- make and investigate mathematical conjectures

Representation

- use representations to model and interpret physical, social, and mathematical phenomena

Communicating the solution will require students to address these expectations from the *Process Standards*:

Communication

- organize and consolidate their mathematical thinking through communication
- communicate their mathematical thinking coherently and clearly to peers, teachers, and others

NSES/Science

The key NSES unifying concept in this Challenge is *Form and function*.

The primary NSES standards category addressed by this Challenge is *E. Science and technology*.

A. Science as inquiry

The skills in standard *A/1 Abilities necessary to do scientific inquiry*, will be required throughout, especially "Design and conduct scientific investigations"

B. Physical science

Among the "Physical Science" standards, a facility with *B/4 Motions and forces* will be necessary for designing the solution

E. Science and technology

Satisfactory completion of the FloDesign Challenge requires all aspects of *E/1 Abilities of technological design*.

F. Science in personal and social perspectives

The problem relates primarily to the standards in the "Science in personal and social perspectives" standards; in particular, *F/3 Natural resources*, *F/4 Environmental quality*, and *F/5 Natural and human-induced hazards*.

+ additional standards

Some student solutions may involve inquiry into the behavior of birds (*C/6 Behavior of organisms*), or into meteorology (broadly related to the Earth Science standards)

Additional standards which may be reinforced are *B/2 Structure and properties of matter*; *E/2 Understanding about science and technology*; and *F/6 Science and technology in local, national, and global challenges*.

Despite their names, the standards *B/6 Interactions of energy and matter* and *D/1 Energy in the earth system* are not closely related to the content in this Challenge.

ITEEA/Technology

The primary ITEEA "Designed world" standard addressed by this Challenge is *16. Energy and power technologies.*

The ITEEA standards grouping most directly applied in this Challenge is *Design*.

The Nature of Technology

2. The core concepts of technology

Y. The stability of a technological system is influenced by all of the components in the system, especially those in the feedback loop.

BB. Optimization is an ongoing process or methodology of designing or making a product and is dependent on criteria and constraints.

Technology and Society

5. The effects of technology on the environment

J. The alignment of technological processes with natural processes maximizes performance and reduces the negative impacts on the environment.

H. When new technologies are developed to reduce the use of resources, considerations of trade-offs are important.

Design

8. The attributes of design

H. The design process includes defining a problem, brainstorming, researching and generating ideas, identifying criteria and specifying constraints, exploring possibilities, selecting an approach, developing a design proposal, making a model or prototype, testing and evaluation the design using specifications, refining the design, creating or making it, and communicating the results.

I. Design problems are seldom presented in a clearly defined form.

9. Engineering design

I. Established design principles are used to evaluate existing designs, to collect data, and to guide the design process.

K. A prototype is a working model used to test a design concept by making actual observations and necessary adjustments.

10. The role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving

J. Technological problems must be researched before they can be solved.

Abilities for a Technological World

11. Apply the design process: *all benchmarks*

13. Assess the impact of products and systems

J. Collect information and evaluate its quality.

The Designed World

16. Energy and power technologies

J. Energy cannot be created or destroyed; however, it can be converted from one form to another.

M. Energy resources can be renewable or nonrenewable.

Standards addressed in the *Cranberry* Challenge

The following subset of the math, science, and technology standards are addressed by this Challenge. This is not a complete listing of all standards.

NCTM/Mathematics

The mathematics content standard most directly addressed in this Challenge is *Algebra*.

Content Standards

Algebra

In designing a solution to this Challenge, ensuring uniformity of application of pesticides/chemicals via a sprinkler system will require students to address these expectations from the *Algebra* standard:

Understand patterns, relations, and functions

- generalize patterns using explicitly defined and recursively defined functions

Determining the just-in-time delivery of water and chemicals to the bog relates to these *Algebra* expectations:

Represent and analyze mathematical situations and structures using algebraic symbols

- use symbolic algebra to represent and explain mathematical relationships

Use mathematical models to represent and understand quantitative relationships

- identify essential quantitative relationships in a situation and determine the class or classes of functions that might model the relationships
- use symbolic expressions, including iterative and recursive forms, to represent relationships arising from various contexts
- draw reasonable conclusions about a situation being modeled.
- approximate and interpret rates of change from graphical and numerical data.

Geometry

Ensuring uniformity of application of pesticides/chemicals via a sprinkler system will require students to address this *Geometry* expectation:

Use visualization, spatial reasoning, and geometric modeling to solve problems

- draw and construct representations of two- and three-dimensional geometric objects using a variety of tools

Students will address this *Geometry* expectation as they analyze the grading and other characteristics of the bog, pond, and ditches:

Use visualization, spatial reasoning, and geometric modeling to solve problems

- visualize three-dimensional objects and spaces from different perspectives and analyze their cross sections

Process Standards

Designing a solution to this Challenge will require students to address these expectations from the *Process Standards*:

Problem Solving

- solve problems that arise in mathematics and in other contexts
- apply and adapt a variety of appropriate strategies to solve problems

Representation

- use representations to model and interpret physical, social, and mathematical phenomena

Communicating the solution will require students to address these expectations from the *Process Standards*:

Communication

- organize and consolidate their mathematical thinking through communication
- communicate their mathematical thinking coherently and clearly to peers, teachers, and others

NSES/Science

The key NSES unifying concept in this Challenge is *Systems, order, and organization*.

The primary NSES standards category addressed by this Challenge is *E. Science and technology*.

A. Science as inquiry

The skills in standard *A/1 Abilities necessary to do scientific inquiry*, will be required throughout, especially as "Design and conduct scientific investigations"

B. Physical science

An understanding of *B/3 Chemical reactions* will be required to address the problem described in the Challenge

C. Life science

The central Life science standard in this Challenge is *C/4 Interdependence of organisms*, especially as it relates to ecosystems

E. Science and technology

Satisfactory completion of the "Cranberry" Challenge requires all aspects of *E/1 Abilities of technological design*.

F. Science in personal and social perspectives

The context of the problem is balancing environmental and economic concerns within an ecosystem. Within the "Science in personal and social perspectives" standards, *F/1 Personal and community health*, *F/4 Environmental quality*, and *F/6 Science and technology* in local, national, and

global challenges are the most directly related to the Challenge.

+ additional standards

The organization overview refers to the conditions and motivations leading to the founding of the federal NRCS and the Cape Cod Cranberry Growers Association. This could lead to investigations related to *F/6 Science and technology in local, national, and global challenges* or *G/3 Historical perspectives.*

Additional standards which may be reinforced are *E/2 Understanding about science and technology* and *F/5 Natural and human-induced hazards*.

ITEEA/Technology

The primary ITEEA "Designed world" standard addressed by this Challenge is *15. Agricultural and related biotechnologies.*

The ITEEA standards grouping most directly applied in this Challenge is *Technology and Society*.

The Nature of Technology

3. The relationships among technologies and the connections between technology and other fields of study

G. Technology transfer occurs when a new user applies an existing innovation developed for one purpose in a different function.

Technology and Society

4. The cultural, social, economic, and political effects of technology

I. Making decisions about the use of technology involves weighing the trade-offs between the positive and negative effects.

5. The effects of technology on the environment

J. The alignment of technological processes with natural processes maximizes performance and reduces the negative impacts on the environment.

K. Humans devise technologies to reduce the negative consequences of other technologies.

6. The role of society in the development and use of technology

J. A number of different factors, such as advertising, the strength of the economy, the goals of a company, and the latest fads contribute to shaping the design of and demand for various technologies.

Design

8. The attributes of design

H. The design process includes defining a problem, brainstorming, researching … refining the design, creating or making it, and communicating the results. {full text under FloDesign}

10. The role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving

I. Research and development is a specific problem-solving approach that is used intensively in business and industry to prepare devices and systems for the marketplace.

J. Technological problems must be researched before they can be solved.

Abilities for a Technological World

11. Apply the design process: *all benchmarks*

The Designed World

15. Agricultural and related biotechnologies

K. Agriculture includes a combination of businesses that use a wide array of products and systems to produce, process, and distribute food, fiber, fuel and chemical and other useful products.

N. The engineering design and management of agricultural systems require knowledge of artificial ecosystems and the effects of technological development on flora and fauna

Standards addressed in the *RSL* Challenge

The following subset of the math, science, and technology standards are addressed by this Challenge. This is not a complete listing of all standards.

NCTM/Mathematics

The mathematics content standard most directly addressed in this Challenge is *Algebra*.

Content Standards

Algebra

Designing a solution to the RSL Challenge will require students to understand concepts related to synchronization and the circadian/24-hour cycle, which are addressed by this *Algebra* expectation:

Understand patterns, relations, and functions

- generalize patterns using explicitly defined and recursively defined functions

In designing a solution to this Challenge, estimating and calculating efficiency measures will require students to address these expectations from the *Algebra* Standards:

Represent and analyze mathematical situations and structures using algebraic symbols

- use symbolic algebra to represent and explain mathematical relationships

Use mathematical models to represent and understand quantitative relationships

- identify essential quantitative relationships in a situation and determine the class or classes of functions that might model the relationships

Measurement

Developing a solution to this Challenge will require students to identify measurement techniques for the collection of light intensity, energy consumption, and color temperature data, which relates to these expectations from the *Measurement* standards:

Understand measurable attributes of objects and the units, systems, and processes of measurement

- make decisions about units and scales that are appropriate for problem situations involving measurement.

Apply appropriate techniques, tools, and formulas to determine measurements

- use unit analysis to check measurement computations.

Data Analysis and Probability

Develop and evaluate inferences and predictions that are based on data

Addressing this Challenge will require students to understand and apply military and industrial lighting standards, which relate to this expectation from the *Data Analysis* standard:

- understand how basic statistical techniques are used to monitor process characteristics in the workplace.

Process Standards

Designing a solution to this Challenge will require students to address these expectations from the *Process Standards*:

Problem Solving

- solve problems that arise in mathematics and in other contexts
- apply and adapt a variety of appropriate strategies to solve problems

Reasoning and Proof

- make and investigate mathematical conjectures

Communicating the solution will require students to address these expectations from the *Process Standards*:

Communication

- organize and consolidate their mathematical thinking through communication
- communicate their mathematical thinking coherently and clearly to peers, teachers, and others

NSES/Science

The key NSES unifying concept in this Challenge is *Change, constancy, and measurement*.

The primary NSES standards category addressed by this Challenge is *A. Science as inquiry*.

A. Science as inquiry

To an even greater degree than most challenges, RSL requires skills throughout this standard. Among the key skills are "Design and conduct scientific investigations" (from *A/1 Abilities necessary to do scientific inquiry*) and "Identify questions and concepts that guide scientific investigations" (from *A/2 Understanding about scientific inquiry*).

B. Physical science

An understanding of B/6 Interactions of energy and matter will be required to address the problem described in the Challenge (this is the portion of the Physical Science standard concerning light)

C. Life science

Understandings within C/6 Behavior of organisms are central to the problem posed by this Challenge.

E. Science and technology

Satisfactory completion of the "Cranberry" Challenge requires all aspects of E/1 Abilities of technological design.

F. Science in personal and social perspectives

The context of the Challenge concerns alleviating problems of people living in an artificial ecosystem. Within the "Science in personal and social perspectives" standards, *F/1 Personal and community health*, *F/4 Environmental quality*, and *F/5 Natural and human-induced hazards* are the most directly related to this Challenge.

+ additional standards

Students will benefit from an understanding of *C/3 Biological evolution* as they explore several root issues, such as bio-stresses and exposure to natural light.

Insofar as the dependence of biology upon energy (and, more specifically, humans upon light) is a central theme, *D/4 Origin and evolution of the universe* would be appropriate background material for this Challenge.

G/3 Historical perspectives can be related to this Challenge, as scientists and engineers have addressed similar problems for centuries, mostly in military contexts (e.g., when people have been stationed at remote outposts, in inhospitable climates, on naval or space vessels, etc.).

ITEEA/Technology

The RSL Challenge contains aspects of two of the ITEEA "Designed world" standards: *18. Transportation technologies* and *19. Manufacturing technologies.* However, it does not focus on benchmarks within these standards.

The ITEEA standards grouping most directly applied in this Challenge is *Design*.

The Nature of Technology

2. The core concepts of technology

- **Y.** The stability of a technological system is influenced by all of the components in the system, especially those in the feedback loop.
- **Z.** Selecting resources involves tradeoffs between competing values, such as availability, cost, desirability and waste.
- **AA**. Requirements involve the identification of the criteria and constraints of a product or system and the determination of how they affect the final design and development.

Technology and Society

5. The effects of technology on the environment

- **J.** The alignment of technological processes with natural processes maximizes performance and reduces the negative impacts on the environment.
- **K.** Humans devise technologies to reduce the negative consequences of other technologies.

Design

8. The attributes of design

- **H.** The design process includes defining a problem, brainstorming, researching … refining the design, creating or making it, and communicating the results. {full text under FloDesign}

9. Engineering design

- **K.** A prototype is a working model used to test a design concept by making actual observations and necessary adjustments.

10. The role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving

- **J.** Technological problems must be researched before they can be solved.

Abilities for a Technological World

11. Apply the design process: *all benchmarks*

12. Use and maintain technological products and systems

- **M.** Diagnose a system that is malfunctioning and use tools, materials, machines, and knowledge to repair it.

The Designed World

{see above}

Standards addressed in the *TTF* Challenge

The following subset of the math, science, and technology standards are addressed by this Challenge. This is not a complete listing of all standards.

NCTM/Mathematics

The mathematics content standards most directly addressed in this Challenge are *Algebra* and *Geometry*.

Content Standards

Algebra

Addressing the stormwater Challenge will require students to make area and volume estimations and computations, which relate to this expectation from the Algebra standard:

Represent and analyze mathematical situations and structures using algebraic symbols

- use symbolic algebra to represent and explain mathematical relationships

Quantifying the effect of trees and plants on air quality relates to this expectation from the *Algebra* standard:

Use mathematical models to represent and understand quantitative relationships

- identify essential quantitative relationships in a situation and determine the class or classes of functions that might model the relationships

Geometry

Analyzing the topography of the park, streets, bioswale, and other features relates to this *Geometry* expectation:

Use visualization, spatial reasoning, and geometric modeling to solve problems

- visualize three-dimensional objects and spaces from different perspectives and analyze their cross sections

Illustrating variations in porosity among different surface areas and materials relates to this *Geometry* expectation:

Use visualization, spatial reasoning, and geometric modeling to solve problems

- use vertex-edge graphs to model and solve problems

Measurement

Environmental measurements, such as those relating to air quality or to moisture (as in the basements of homes) relate to this *Measurement* expectation:

Understand measurable attributes of objects and the units, systems, and processes of measurement

- make decisions about units and scales that are appropriate for problem situations involving measurement.

Process Standards

Communicating their solution to this Challenge will require students to address these expectations from the *Process Standards*:

Communication

- organize and consolidate their mathematical thinking through communication
- communicate their mathematical thinking coherently and clearly to peers, teachers, and others

Representation

- create and use representations to organize, record, and communicate mathematical ideas
- use representations to model and interpret physical, social, and mathematical phenomena

NSES/Science

The key NSES unifying concept in this Challenge is *Systems, order, and organization*.

The primary NSES standards category addressed by this Challenge is *F. Science in personal and social perspectives*.

A. Science as inquiry

Successfully addressing the problem in the TTF Challenge will require skills throughout this standard, particularly "Design and conduct scientific investigations" and "Use technology and mathematics to improve investigations and communications."

B. Physical science

Among the "Physical Science" standards, an understanding of *B/2 Structure and properties of matter*—especially the physical properties of both water and the materials into which it flows—will be necessary for designing solutions to the problem.

E. Science and technology

Satisfactory completion of this Challenge requires all aspects of *E/1 Abilities of technological design*.

F. Science in personal and social perspectives

This Challenge addresses all six of the "Science in personal and social perspectives" standards.

+ additional standards

Depending the degree to which impacts on plants and animals is emphasized, content within *C/4 Interdependence of organisms* and *C/6 Behavior of organisms* may be beneficial

G/1 Science as a human endeavor isn't central to addressing the immediate problems in TTF, but this Challenge could be a context in which to study its concepts.

ITEEA/Technology

The primary ITEEA "Designed world" standard addressed by this Challenge is *20. Construction technologies.*

The ITEEA standards groupings most directly applied in this Challenge are *Technology and Society* and *Abilities for a Technological World*.

Technology and Society

5. The effects of technology on the environment

G. Humans can devise technologies to conserve water, soil, and energy through such techniques as reusing, reducing, and recycling.

6. The role of society in the development and use of technology

I. The decision whether to develop a technology is influenced by societal opinions and demands, in addition to corporate cultures.

Design

8. The attributes of design

H. The design process includes defining a problem, brainstorming, researching … refining the design, creating or making it, and communicating the results. {full text under FloDesign}

10. The role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving

J. Technological problems must be researched before they can be solved.

Abilities for a Technological World

11. Apply the design process: *all benchmarks*

12. Use and maintain technological products and systems

L. Document processes and procedures and communicate them to different audiences using appropriate oral and written techniques.

M. Diagnose a system that is malfunctioning and use tools, materials, machines, and knowledge to repair it.

13. Assess the impact of products and systems

M. Design forecasting techniques to evaluate the results of altering natural systems.

The Designed World

15. Agricultural and related biotechnologies

M. Conservation is the process of controlling soil erosion, reducing sediment in waterways, conserving water, and improving water quality.

20. Construction technologies

J. Infrastructure is the underlying base or basic framework of a system.

Standards addressed in the *City of Tucson / SPG Solar* Challenge

The following subset of the math, science, and technology standards are addressed by this Challenge. This is not a complete listing of all standards.

NCTM/Mathematics

The mathematics content standard most directly addressed in this Challenge is *Algebra.*

Content Standards

Algebra

Designing a solution to the SPG Challenge will require students to understand concepts addressed by this Algebra expectation:

Understand patterns, relations, and functions

- generalize patterns using explicitly defined and recursively defined functions

Represent and analyze mathematical situations and structures using algebraic symbols

- use symbolic algebra to represent and explain mathematical relationships

Use mathematical models to represent and understand quantitative relationships

- identify essential quantitative relationships in a situation and determine the class(es) of functions that might model the relationships
- use symbolic expressions, including iterative and recursive forms, to represent relationships arising from various contexts
- draw reasonable conclusions about a situation being modeled.
- approximate and interpret rates of change from graphical and numerical data.

Geometry

Analyze characteristics and properties of two- and three-dimensional geometric shapes and develop mathematical arguments about geometric relationships

Use visualization, spatial reasoning, and geometric modeling to solve problems

- draw and construct representations of two- and three-dimensional geometric objects using a variety of tools

Measurement

Understand measurable attributes of objects and the units, systems, and processes of measurement

- make decisions about units and scales that are appropriate for problem situations involving measurement.

Apply appropriate techniques, tools, and formulas to determine measurements

- understand and use formulas for the area, surface area, and volume of geometric figures, including cones, spheres, and cylinders
- use unit analysis to check measurement computations.

Process Standards

Problem Solving

- solve problems that arise in mathematics and in other contexts
- apply and adapt a variety of appropriate strategies to solve problems

Communication

- organize and consolidate their mathematical thinking through communication
- communicate their mathematical thinking coherently and clearly to peers, teachers, and others

Representation

- create and use representations to organize, record, and communicate mathematical ideas
- use representations to model and interpret physical, social, and mathematical phenomena

NSES/Science

The key NSES unifying concept in this Challenge is *Form and Function*.

The primary NSES category addressed by this Challenge is *B. Physical Science*.

A. Science as inquiry

The skills in standard A/1, Abilities necessary to do scientific inquiry, will be required throughout, especially "Design and conduct scientific investigations"

B. Physical science

An understanding of three "Physical Science' standards will be required to successfully address the "City of Tucson / SPG Solar" Challenge: B/4 Motions and forces; B/5 Conservation of energy and increase in disorder; and B/6 Interactions of energy and matter.

C. Life science

An important Life Science concept underlying this Challenge is the relationship between people (as organisms) and their natural environment; C/5 Matter, energy, and organization in living systems and C/6 Behavior of organisms.

E. Science and technology

Satisfactory completion of this Challenge requires all aspects of E/1 Abilities of technological design.

F. Science in personal and social perspectives

Directly or indirectly, this Challenge addresses all six of the "Science in personal and social perspectives" standards. Among these, F/3 Natural resources and F/6 Science and technology in local, national, and global challenges are most central to the Challenge.

+ additional standards

While C/5 and C/6 are the Life Science standards most directly related to this Challenge, ecosystems, a topic which might be included as background information, is also a part of C/4 Interdependence of organisms.

ITEEA/Technology

The primary ITEEA "Designed world" standard addressed by this Challenge is *16. Energy and power technologies.*

The ITEEA standards grouping most directly applied in this Challenge is *Abilities for a Technological World*.

The Nature of Technology

2. The core concepts of technology

X. Systems, which are the building blocks of technology, are embedded within larger technological, social, and environmental systems.

Y. The stability of a technological system is influenced by all of the components in the system, especially those in the feedback loop.

BB. Optimization is an ongoing process or methodology of designing or making a product and is dependent on criteria and constraints.

FF. Complex systems have many layers of controls and feedback loops to provide information.

Technology and Society

5. The effects of technology on the environment

H. When new technologies are developed to reduce the use of resources, considerations of trade-offs are important.

J. The alignment of technological processes with natural processes maximizes performance and reduces the negative impacts on the environment.

K. Humans devise technologies to reduce the negative consequences of other technologies.

Design

8. The attributes of design

H. The design process includes defining a problem, brainstorming, researching and generating ideas, identifying criteria and specifying constraints, exploring possibilities, selecting an approach, developing a design proposal, making a model or prototype, testing and evaluation the design using specifications, refining the design, creating or making it, and communicating the results.

9. Engineering design

K. A prototype is a working model used to test a design concept by making actual observations and necessary adjustments.

L. The process of engineering design takes into account a number of factors.

10. The role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving

J. Technological problems must be researched before they can be solved.

Abilities for a Technological World

11. Apply the design process

O. Refine a design by using prototypes and modeling to ensure quality, efficiency, and productivity of the final product.

P. Evaluate the design solution using conceptual, physical, and mathematical models at various intervals of the design process in order to check for proper design and to note where improvements are needed.

Q. Develop and produce a product or system using a design process.

R. Evaluate final solutions and communicate observation, processes, and results of the entire design process, using verbal, graphic, quantitative, virtual, and written means, in addition to three-dimensional models.

12. Use and maintain technological products and systems

L. Document processes and procedures and communicate them to different audiences using appropriate oral and written techniques.

13. Assess the impact of products and systems

J. Collect information and evaluate its quality.

K. Synthesize data, analyze trends, and draw conclusions regarding the effect of technology on the individual, society, and the environment.

L. Use assessment techniques, such as trend analysis and experimentation to make decisions about the future development of technology.

The Designed World

16. Energy and power technologies

M. Energy resources can be renewable or nonrenewable.

N. Power systems must have a source of energy, a process, and loads.

Standards addressed in the *Johnson&Johnson* Challenge

The following subset of the math, science, and technology standards are addressed by this Challenge. This is not a complete listing of all standards.

NCTM/Mathematics

The math content standard most directly addressed in this Challenge is *Data Analysis and Probability*.

Content Standards

Designing a solution to this Challenge will require students to construct and use formulas, which is addressed by these Algebra expectations:

Algebra

Understand patterns, relations, and functions

- generalize patterns using explicitly defined and recursively defined functions

Represent and analyze mathematical situations and structures using algebraic symbols

- use symbolic algebra to represent and explain mathematical relationships

Use mathematical models to represent and understand quantitative relationships

- draw reasonable conclusions about a situation being modeled.

Designing a solution to the J&J Challenge will require students to analyze formulations, which relates to these Measurement and Data Analysis and Probability expectations:

Measurement

Understand measurable attributes of objects and the units, systems, and processes of measurement

- make decisions about units and scales that are appropriate for problem situations involving measurement.

Apply appropriate techniques, tools, and formulas to determine measurements

- use unit analysis to check measurement computations.

Data Analysis and Probability

Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them

- compute basic statistics and understand the distinction between a statistic and a parameter.

Select and use appropriate statistical methods to analyze data

Develop and evaluate inferences and predictions that are based on data

- understand how sample statistics reflect the values of population parameters and use sampling distributions as the basis for informal inference
- understand how basic statistical techniques are used to monitor process characteristics in the workplace.

Process Standards

Problem Solving

- solve problems that arise in mathematics and in other contexts
- apply and adapt a variety of appropriate strategies to solve problems

Communication

- organize and consolidate their mathematical thinking through communication
- communicate their mathematical thinking coherently and clearly to peers, teachers, and others

Representation

- create and use representations to organize, record, and communicate mathematical ideas

NSES/Science

The key NSES unifying concept in this Challenge is *Form and Function*.

The primary NSES standards category addressed by this Challenge is *F. Science in personal and social perspectives*.

A. Science as inquiry

Successfully addressing the problem in the J&J Challenge will requires skills throughout this standard, particularly "Design and conduct scientific investigations" and (to a lesser degree) "Use technology and mathematics to improve investigations and communications."

B. Physical science

Among the "Physical Science" standards, an understanding of B/2 Structure and properties of matter will be necessary for designing solutions to the problem. This is true of the development of the product (whose properties are to include absorbency and non-greasiness) and the packaging of the product.

E. Science and technology

Satisfactory completion of this Challenge requires all aspects of E/1 Abilities of technological design.

F. Science in personal and social perspectives

This Challenge addresses "Science in personal and social perspectives" in two distinct ways. First, the development of the product relates to F/1 Personal and community health insofar as a nonmedicinal product should not cause other health problems (e.g., those caused by steroids). Second, F/3 Natural resources, F/4 Environmental quality, and especially F/5 Natural and human-induced hazards and F/6 Science and

technology in local, national, and global challenges are addressed when considering the "environmental and social issues involved in bringing a new product to market."

G. History and nature of science

Standard G/1 Science as a human endeavor is addressed throughout this Challenge, as the problem-solvers deal with tradeoffs and attempt to balance (sometimes conflicting) priorities.

+ additional standards

This Challenge relates broadly to the standards in C / Life Science insofar as the product being developed is to be applied to human skin. However, human anatomy is not specifically addressed among these high-school standards.

Aspects of B/3 Chemical reactions may be included as background information for this Challenge.

Aspects of E/2 Understanding about science and technology are addressed in this Challenge alongside G/1 Science as a human endeavor.

ITEEA/Technology

The primary ITEEA "Designed world" standard addressed by this Challenge is *19. Manufacturing technologies.*

The ITEEA standards groupings most directly applied in this Challenge are *Design* and *Technology and Society*.

The Nature of Technology

1. The characteristics and scope of technology

L. Inventions and innovations are the result of specific, goal-directed research.

2. The core concepts of technology

Z. Selecting resources involves tradeoffs between competing values, such as availability, cost, desirability and waste.

AA. Requirements involve the identification of the criteria and constraints of a product or system…

DD. Quality control is a planned process to ensure that a product, service, or system meets established criteria.

3. The relationships among technologies and the connections between technology and other fields of study

H. Technological innovation often results when ideas, knowledge, or skills are shared….

Technology and Society

4. The cultural, social, economic, and political effects of technology

I. Making decisions about the use of technology involves weighing the trade-offs between the positive and negative effects.

J. Ethical considerations are important in the development, selection and use of technologies.

5. The effects of technology on the environment

G. Humans can devise technologies to conserve water, soil, and energy …

L. Decisions regarding the implementation of technologies involve the weighing of trade-offs between predicted positive and negative effects on the environment.

6. The role of society in the development and use of technology

J. A number of different factors, such as advertising, the strength of the economy, the goals of a company, and the latest fads contribute to shaping the design of and demand for various technologies.

Design

8. The attributes of design

H. The design process includes defining a problem, brainstorming, researching and generating ideas, identifying criteria and specifying constraints…

I. Design problems are seldom presented in a clearly defined form.

K. Requirements of a design, such as criteria, constraints, and efficiency, sometimes compete with each other.

9. Engineering design

J. Engineering design is influenced by personal characteristics, such as creativity, resourcefulness, and the ability to visualize and think abstractly.

10. The role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving

J. Technological problems must be researched before they can be solved.

L. Many technological problems require a multidisciplinary approach.

Abilities for a Technological World

11. Apply the design process

P. Evaluate the design solution using conceptual, physical, and mathematical models …

Q. Develop and produce a product or system using a design process.

R. Evaluate final solutions and communicate observation, processes, and results…

12. Use and maintain technological products and systems

L. Document processes and procedures and communicate them to different audiences using appropriate oral and written techniques.

13. Assess the impact of products and systems

J. Collect information and evaluate its quality.

L. Use assessment techniques, such as trend analysis and experimentation to make decisions about the future development of technology.

The Designed World

{see above}