Off-the-Shelf Lesson:
Well-Defined Criteria and Constraints

Teaching Time: 2-3 Class Periods (assuming 50 minute periods)

Instructional Settings:
- Classroom with a computer and projector
- Computer lab (Uncover Your Ideas) with internet connection

Lesson Question:

- How can we make sure projects are described well enough to design a good solution to a problem?

Lesson Key Concepts (DCI & CCC)	• Criteria are characteristics that are maximized in a successful solution. They are used to determine which best solves the problem.
	• Constraints are characteristics that must be met for a solution to be successful. They are used to determine which proposed solutions solve the problem.
	• Useful criteria and constraints are more likely to lead to successful solutions.
	  ○ Useful criteria and constraints are measurable.
	  ○ Useful criteria and constraints must be based on:
	    ■ scientific principles that are relevant to the problem (e.g understanding of how gravity moves water).
	    ■ other relevant knowledge (e.g. needs and desires, times, materials, costs, safety and human and environmental impact).

Lesson Key Practices	• Identify and create well defined criteria and constraints for a given problem

Learning Performances

1. Students will ask questions about a problem within a system to clarify the relevant knowledge, scientific principle(s) and other information needed to create well-defined criteria and constraints.
2. Student will develop well-defined criteria and constraints.
3. Students will use models and provided information to evaluate criteria and constraints are well-defined (and include scientific principles, relevant knowledge, and are measurable).
4. Students will construct an argument based on evidence for why well-defined criteria and constraints are necessary for a well-defined problem and a successful solution.

NGSS Connections

Primary Subcomponents

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Practice name ● none	**ETS1.A: Defining and Delimiting Engineering Problems** ● The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions. (MS-ETS1-1)	**CCC name** ● none

Lesson Introduction:

Students explore the importance of clearly defining the **criteria** and **constraints** in order to have a successful solution. By clearly defining the criteria and constraints, the solution you arrive at is more likely to be successful. When these criteria and constraints are poorly defined it is more likely the solution will not actually address the problem, fail to meet the needs of the stakeholders, or be less successful than other potential solutions.

Criteria are clear goals that a successful final product or system should meet and generally reflect the needs of the groups involved. They address things such as how the system needs to function, and the cost and durability of the solution. Constraints are the limitations within which the problem must be solved. Constraints can be related to many conditions including physical, economic, environmental, aesthetic or time. Well defined criteria and constraints should be quantifiable when possible and be based on scientific principles and other relevant knowledge that are likely to limit possible solutions (National Research Council, 2012).

In student language, constraints are things you MUST do to solve the problem, they are deal breakers. If constraints are not met the solution is not acceptable. Criteria are the goals we want the solution to meet as much possible. Once you decide what the 'deal-breakers' (Constraints) are, criteria are the important parts of a solution that can be compared between different design options to choose the best one.

Science Words
This Lesson
Criteria Constraints Well-defined

Advance Preparation

- Prepare copies of student resources as needed (see phase summaries).
- Check internet connections

Safety Considerations

None

Mi-STAR Lesson Structure

Anchoring Experience

Phase Summary:

Students look at examples of products that did not perform the way they were intended.

Resources Needed for this Instructional Phase:

- OTS_CriteriaConstraints_Slides_PORTAL

Student Steps:

1. Students consider an example of a solution that would be considered by most to be less than ideal, by examining the image in OTS_CriteriaConstraints_Slides_PORTAL.

2. Students connect their prior knowledge and current thinking to the lesson key concepts by thinking about questions such as the following:

Example Guiding Questions
Was this design successful? How do you know?
What may have helped this idea be more successful or perform better?
Have you ever bought something that did not work the way it was supposed to or broke right away?

3. Individually, students record their answers to the lesson question:
    - How can we make sure projects are described well enough to design a good solution to a problem?

Uncover Your Ideas

Phase Summary:

Students participate in a purposely unfair design competition that uncovers the importance of well-defined criteria and constraints to having a successful solution.

Resources Needed for this Instructional Phase:

- OTS_CriteriaConstraints_Slides_PORTAL
- Per Group
  - 10 pieces copier paper
  - 20 cm length of scotch tape
  - Scissors
  - Meter stick (preferred) or ruler
  - Hair dryer
  - Powerful fan: Box fan, leaf blower etc
  - For ½ of groups: OTS_Uncover_Student_WellDefinedGuide
  - For ½ of groups: OTS_Uncover_Student_PoorlyDefinedGuide

Student Steps:

1. Students are challenged to a design competition using the following scenario:

   "Many cities have towers for either practical purposes or to celebrate humankind's imagination and engineering skills. The principal of our school wants to highlight students' creativity and design skills by having students build paper towers and then display them around the school. In the past when we have tried to do displays like the towers, they looked very messy and were always falling over, or would not fit on the display shelves. We have been asked to create towers that are attractive and stand up to the breezes in the hallway."

2. The class is divided into small groups (3-4 students). One half of the groups obtain OTS_Uncover_Student_WellDefinedGuide and the other half of the groups obtain OTS_Uncover_Student_PoorlyDefinedGuide.

   Teacher Note: Students should be oriented to the handouts, and the instructions on them, but are not told that there are two versions. Encourage students to read silently and remain with their group; to reduce the likelihood of students discovering there are 2 versions of the student guide. Additionally, keep track of which group has which resource, so the effect of well defined criteria and constraints can be illustrated later in the lesson.

3. Student groups build their towers based on the information on the student guide.

4. In small groups, students are instructed to use their student guide to determine if their tower was successful by describing whether or not it meets the "your tower must" section

and also determine how desirable their tower was by scoring their own tower. They should be prepared to justify their score later in the class discussion.

Teacher Note: Students are still not officially aware that there are two different student guides. This will come out in the share portion of the lesson.

Share Your Ideas

Phase Summary:

Students share if they had a successful solution and should be able to display their tower. They attempt to justify their answer by using evidence from the student guide they have been given.

Resources Needed for this Instructional Phase:

- Per Class
  - none
- Per Group
  - OTS_Uncover_Student_WellDefinedGuide
  - OTS_Uncover_Student_PoorlyDefinedGuide
  - White Boards/Scientists Notebook
- Per Student
  - none
- Teacher Resources
  - OTS_Slides
  - OTS_Uncover_Teacher_CriteriaConstraintGuide
  - OTS_CC_Share_Teacher_Towers on the shelf

Student Steps:

1. Student groups take turns sharing the results of the tower design. They share if they had a successful design or not based on the guide their team was given. Students will observe that some groups will be more successful than others, because they had more specific information. Other groups will have a more difficult time designing a successful solution because they had unclear and poorly defined information.

   Teacher Note: Have students share their results using whiteboards or chart paper so they can easily recognize that different groups are working with different student design guidelines.

2. Students should use scores as evidence from the student guide in their explanations.

3. To see firsthand how the different criteria and constraints affected their likelihood of success, students should put their towers on a 50 cm shelf to test how their towers fit.

   Teacher Note: If a shelf is unavailable use OTS_CC_Share_Teacher_Towers on the shelf to illustrate a common outcome from the two guides.

Example Guiding Questions	Example Student Answers
Why did some teams fail to fit on the shelf?	*When the "your tower must" section was vague, teams were more likely to not fit on the shelf.*
Was this design challenge fair?	*No, students given guide A (the well defined guide) were more likely to succeed.*

4. Students experience how unforeseen phenomena can affect the success of their solution through the addition of strong winds. Students are now given the following new information.

   "Under the right conditions, strong winds can blow directly down the hallway through the open door/window. The towers need to be able to stand up in these high winds."

5. (Optional) Students anchor their understanding of the strong wind conditions by watching https://www.youtube.com/watch?v=iHeWkgkmD1k, which shows strong winds blowing through a room.

6. Test the towers' ability to stand in high wind, by subjecting them to the powerful fan/leaf blower from approximately 5 meters away.

   Teacher Note: It is important that students do not get the ability to refine their designs before this test, all or nearly all towers should fail during this test. Student groups will realize that it is highly unlikely to have a successful design when information is missing, even when criteria and constraints are well defined.

7. Students should look for similarities and differences using these questions:
   - What similarities do you see in the scores shared from the Uncover phase?

- What differences do you see in the scores from the Uncover phase?

8. As students bring up the concepts of **criteria** and **constraints**, lead students to define these science words using questions similar to the following:

Example Guiding Questions	Example Student Answers
How do we know if our tower design was a successful solution?	*Successful towers* must meet the requirements in the “your towers must” section of the student guide.
What did we need to know to give a tower an accurate score?	*Some categories gave specific directions or examples of what made a tower better or worse.*
What did you need to know to make a successful tower design?	*Some things had to be definite and some things had a choice/rating.*
What kind of things were “must haves” for the tower (constraints)? What kinds of things should your tower do (criteria)?	*Absolute expectations were the time limit, height, and the supplies used.* *Things that had a range of choices were looking nice, using materials wisely, and standing up to a breeze.*
After the leaf blower/strong fan	
How many towers survived after the strong winds? What effect does missing information have on creating a successful solution to a design challenge?	*Most towers will fail at this point. We need to have all the information to make our designs successful.*

What type of information is needed to design a good solution to a problem?	*We need to have specific information like what the tower needs to do, sometimes based on facts, research, or scientific ideas. We need complete information ahead of time.*

9. Students check their explanations against the list of science words below. If necessary, students are introduced to any unused science words; first by prompting students with questions that lead them to the terms similar to the following, and then by providing the definitions.

    Criteria: The goals we want the solution to meet as much possible.
    Constraints: Things that if they are not met, the solution is not acceptable.
    Well-defined: Being measurable, on an appropriate scale, and based on relevant scientific principles.

    In whole group, students formalize their explanation from the consensus discussion using the science words above.

    Teacher note: The goal of the previous two steps is to prepare students to use correct and appropriate terminology when explaining **this lesson's key concepts** and relationships. If needed, use other resources (readings, websites, textbook sections, grade appropriate science articles) along with note-taking organizers or student guides to help students connect their thinking to the accepted body of scientific knowledge and terminology.

Connect Your Ideas

Phase Summary:

In this phase, students will learn about the Tacoma Narrows Bridge and the Mackinac Bridge and consider why one bridge led to a successful solution (well-defined criteria and constraints) and the other lead to an unsuccessful solution (poorly-defined criteria and constraints).

Resources Needed for this Instructional Phase:

- Per Class
    - Internet links to Mackinac Bridge (https://www.youtube.com/watch?v=keUzZJb45tQ) and Tacoma Narrows

Bridge
(https://www.youtube.com/watch?v=j-zczJXSxnw&feature=youtu.be&t=122)

- Per Group
  - none
- Per Student
  - OTS_CC_Connect_Student_TwoBridgesCaseStudy
- Teacher Resources
  - Exemplar Mackinac Bridge and Tacoma Bridge Fact Sheet and Two Bridge Fact Study
  - OTS_Connect_Teacher_TwoBridges
  - OTS_Slides

Student Steps:

1. Students watch two video clips showing the Mackinac Bridge and the Tacoma Narrows Bridge. Students view the video clips using the internet links to Mackinac Bridge (https://www.youtube.com/watch?v=keUzZJb45tQ) and Tacoma Narrows Bridge (https://www.youtube.com/watch?v=j-zczJXSxnw&feature=youtu.be&t=12).

2. Students look for similarities and differences between the Mackinac Bridge and Tacoma Narrows Bridge using OTS_CriteriaConstraints_Slides so that students are familiar with both bridges.
   - Internet links to Mackinac Bridge (https://www.youtube.com/watch?v=keUzZJb45tQ) and Tacoma Narrows Bridge (https://www.youtube.com/watch?v=j-zczJXSxnw&feature=youtu.be&t=12)

3. Students read the Mackinac Bridge and Tacoma Bridge Fact Sheet in OTS_CC_Connect_Student_TwoBridgesCaseStudy, and practice identifying criteria and constraints by completing part A.

4. Students demonstrate their understanding of the relationship between well defined criteria and constraints and successful solutions by completing part B of the Two Bridge Case Study explaining which bridge was a more successful engineering solution.

5. Students use the research provided in the case study to revise the criteria and constraints listed in Part C. Revised criteria and constraints should reflect understanding of the importance of well defined criteria and constraints..

   Teacher Note: Students can do additional research about the Tacoma Narrows Bridge and include additional well defined criteria and constraints.

Check Your Progress

Phase Summary:

Students will individually use an image of a bent cell phone to develop well-defined criteria and constraints that could have lead to a more successful phone design.

Resources Needed for this Instructional Phase:

- Per Class
  - Image of bent cell phone
- Per Group
  - None
- Per Student
  - OTS_CC_Check_Student_BendingCellphones
- Teacher Resources
  - OTS_Slides
  - OTS_CC_Check_Teacher_ExemplarBendingCellphones

Student Steps:

1. Students view an image of a bent cell phone.

2. Students are given a list of criteria and constraints that could be in place for the redesign.

3. Students must decide which criteria and constraints are well defined **and** would best solve the problem of the bending of cell phones.

4. Students refer back to the initial answers that they recorded in the Anchoring Experience phase.
   - How can we make sure projects are described well enough to design a good solution to a problem?

5. Students respond to a prompt similar to the following:
   - Explain how the activities in this lesson confirmed, challenged, or otherwise changed your original ideas about the lesson question.

Sources

1. APS Physics. 2016. "November 7, 1940: Collapse of the Tacoma Narrows Bridge". https://www.aps.org/publications/apsnews/201611/physicshistory.cfm. Accessed 2018

