TOPIC
Engineering Design and Problem Solving

KEY QUESTION
What general procedures are the best to use to choose a bridge type to build across any span and how can Mn/DoT use this procedure to replace other bridges in Minnesota? The I-35 W bridge collapse is used as a motivating example for the need to replace or repair bridges.

LEARNING GOALS
Students will:
• Using different type of background information (e.g. table of different type of bridges) and data (visual and numeric) to create procedures that can result the best design to fit the needs of clients.
• Engineering design with constraints to create a model to build a bridge in a particular location.
• Make decisions about whether or not a solution meets the needs of a client
• Communicate the solution clearly to the client

GUIDING DOCUMENTS
This activity has the potential to address many mathematics and science standards, as well as address engineering principles. Please see pages 4-6 for a complete list of mathematics and science standards.

RECOMMENDED SUPPLIES FOR ALL MODEL-ELICITING ACTIVITIES
It is recommended to have all of these supplies in a central location in the room. It is recommended to let the students know that they are available, but not to encourage them to use anything in particular.

• Overhead transparencies and transparency markers/pens or whiteboards and markers, posterboards, or other presentation tools such as a document camera.

• Calculators
• Rulers, scissors, tape
• Markers, colored pencils, pencils
• Construction paper, graph paper, lined paper
• Paper towels or tissues (for cleaning transparencies)
• Manila folders or paper clips for collecting the students’ work
• Optional: Computers with programs such as Microsoft Word and Excel

WHAT ARE MODEL-ELICITING ACTIVITIES (MEAs)?
Model-Eliciting Activities are problem activities explicitly designed to help students develop conceptual foundations for deeper and higher order ideas in mathematics, science, engineering, and other disciplines. Each task asks students to mathematically interpret a complex real-world situation and requires the formation of a mathematical description, procedure, or method for the purpose of making a decision for a realistic client. Because teams of students are producing a description, procedure, or method (instead of a one-word or one-number answer), students’ solutions to the task reveal explicitly how they are thinking about the given situation.

THE Bridge MEA CONSISTS OF FOUR COMPONENTS:
1) Newspaper article: Students individually read the newspaper article to become familiar with the context of the problem. This handout is on page 7.
2) Readiness questions: Students individually answer these reading comprehension questions about the newspaper article to become even more familiar with the context and beginning thinking about the problem. This handout is on page 8.
3) Problem statement: In teams of three or four, students work on the problem statement for 45 – 90 minutes. This time range depends
on the amount of self-reflection and revision you want the students to do. It can be shorter if you are looking for students’ first thoughts, and can be longer if you expect a polished solution and well-written letter. The handouts are on pages 9-20.

4) **Process of sharing solutions:** Each team writes their solution in a letter or memo to the client. Then, each team presents their solution to the class. Whole class discussion is intermingled with these presentations to discuss the different solutions, the mathematics involved, and the effectiveness of the different solutions in meeting the needs of the client.

In totality, each MEA takes approximately 2-3 class periods to implement, but can be shortened by having students do the individual work during out-of-class time. The Presentation Form can be useful and is explained on page 4 and found on page 22.

**RECOMMENDED PROGRESSION OF THE Bridge MEA**

While other implementation options are possible for MEAs, it is recommended that the MEA be implemented in a cooperative learning format. Numerous research studies have proven cooperative learning to be effective at improving student achievement, understanding, and problem solving skills. In this method students will complete work individually (Newspaper article and readiness questions; as well as initial thoughts on the problem statement) and then work together as a group. This is important because brainstorming works best when students have individual time to think before working as a group. Students can be graded on both their individual and group contributions. Social skills’ discussion at the beginning of the MEA and reflection questions at the end of the MEA are also essential aspects of cooperative learning.

**Social Skills (3 - 5 minutes)**

Students must be taught how to communicate and work well in groups. Several social skills that are essential to group work are decision-making, asking questions, and communicating and listening. The teacher can show part of a YouTube video and discuss aspects of these skills before beginning the MEA. (http://www.youtube.com/user/flowmathematics)

**Newspaper Article and Readiness Questions:**

The purpose of the newspaper article and the readiness questions is to introduce the students to the context of the problem.

(10 minutes): Give the article and the questions to the students the day before for homework. Then, in the next class, discuss as a class the answers to the readiness questions before beginning to discuss the problem statement.

**Problem Statement:**

You may want to read the problem statement to the students and then identify as a class: a) **the client that the students are working for** and b) **the product that the students are being asked to produce**. Once you have addressed the points above, allow the students to work on the problem statement. Let the students know that they will be sharing their solution to the rest of the class. Tell students that you will randomly pick a group member to present for each group. Tell the students that they need to make sure that everyone understands their group’s solution so they need to be sure to work together well. The group member who will present can be picked by assigning each group member a number.

**Working on the Problem Statement (35-50 minutes):** Place the students in teams of three or four. Students should begin to work by sharing their initial ideas for solving the problem. If you already use teams in your classroom, it is best if you continue with these same teams since results for MEAs are better when the students have already developed a working relationship with their team members. If you do not use teams in your classroom and classroom management is an issue, the teacher may form the teams. If classroom management is not an issue, the students may form their own
teams. You may want to have the students choose a name for their team to promote unity.

**Teachers’ role:** As they work, your role should be one of a facilitator and observer. Avoid questions or comments that steer the students toward a particular solution. Try to answer their questions with questions so that the student teams figure out their own issues. Also during this time, try to get a sense of how the students are solving the problem so that you can ask them questions about their solutions during their presentations.

**Presentations of Solutions** (15-30 minutes): The teams present their solutions to the class. There are several options of how you do this. Doing this electronically or assigning students to give feedback as out-of-class work can lessen the time spent on presentations. If you choose to do this in class, which offers the chance for the richest discussions, the following are recommendations for implementation. Each presentation typically takes 3 – 5 minutes. You may want to limit the number of presentations to five or six or limit the number of presentations to the number of original (or significantly different) solutions to the MEA.

Before beginning the presentations, encourage the other students to not only listen to the other teams’ presentations but also to a) **try to understand the other teams’ solutions** and b) **consider how well these other solutions meet the needs of the client.** You may want to offer points to students that ask ‘good’ questions of the other teams, or you may want students to complete a reflection page (explanation – page 4, form – page 23) in which they explain how they would revise their solution after hearing about the other solutions. As students offer their presentations and ask questions, whole class discussions should be intermixed with the presentations in order to address conflicts or differences in solutions. When the presentations are over, collect the student teams’ memos/letters, presentation overheads, and any other work you would like to look over or assess.

**ASSESSMENT OF STUDENTS’ WORK**

You can decide if you wish to evaluate the students’ work. If you decide to do so, you may find the following Assessment Guide Rubric helpful:

**Performance Level Effectiveness:** Does the solution meet the client’s needs?

**Requires redirection:** The product is on the wrong track. Working longer or harder with this approach will not work. The students may need additional feedback from the teacher.

**Requires major extensions or refinements:** The product is a good start toward meeting the client’s needs, but a lot more work is needed to respond to all of the issues.

**Requires editing and revisions:** The product is on a good track to be used. It still needs modifications, additions or refinements.

**Useful for this specific data given, but not shareable and reusable OR Almost shareable and reusable but requires minor revisions:** No changes will be needed to meet the immediate needs of the client for this set of data, but not generalized OR Small changes needed to meet the generalized needs of the client.

**Share-able or re-usable:** The tool not only works for the immediate solution, but it would be easy for others to modify and use in similar situations. OR The solution goes above and beyond meeting the immediate needs of the client.

**IMPLEMENTING AN MEA WITH STUDENTS FOR THE FIRST TIME**

You may want to let students know the following about MEAs:

- MEAs are longer problems; there are no immediate answers. Instead, students should
expect to work on the problem and gradually revise their solution over a period of 45 minutes to an hour.

• MEAs often have more than one solution or one way of thinking about the problem.

• Let the students know ahead of time that they will be presenting their solutions to the class. Tell them to prepare for a 3-5 minute presentation, and that they may use overhead transparencies or other visuals during their presentation.

• Let the students know that you won’t be answering questions such as “Is this the right way to do it?” or “Are we done yet?” You can tell them that you will answer clarification questions, but that you will not guide them through the MEA.

• Remind students to make sure that they have returned to the problem statement to verify that they have fully answered the question.

• If students struggle with writing the letter, encourage them to read the letter out loud to each other. This usually helps them identify omissions and errors.

OBSERVING STUDENTS AS THEY WORK ON THE BRIDGE MEA
You may find the Observation Form (page 21) useful for making notes about one or more of your teams of students as they work on the MEA. We have found that the form could be filled out “real-time” as you observe the students working or sometime shortly after you observe the students. The form can be used to record observations about what concepts the students are using, how they are interacting as a team, how they are organizing the data, what tools they use, what revisions to their solutions they may make, and any other miscellaneous comments.

PRESENTATION FORM (Optional)
As the teams of students present their solutions to the class, you may find it helpful to have each student complete the presentation form on page 22. This form asks students to evaluate and provide feedback about the solutions of at least two teams. It also asks students to consider how they would revise their own solution to the Paper Airplane MEA after hearing of the other teams’ solutions.

STUDENT REFLECTION FORM
You may find the Student Reflection Form (page 23) useful for concluding the MEA with the students. The form is a debriefing tool, and it asks students to consider the concepts that they used in solving the MEA and to consider how they would revise their previous solution after hearing of all the different solutions presented by the various teams. Students typically fill out this form after the team presentations.

STANDARDS ADDRESSED
NCTM Mathematics Standards
Numbers and Operations:
• Understand and use ratios and proportions to represent quantitative relationships
• Judge the reasonableness of numerical computations and their results

Algebra
• Represent, analyze, and generalize a variety of patterns with tables, graphs, words, and, when possible, symbolic rules
• Relate and compare different forms of representation for a relationship
• 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

Geometry
• Use geometric ideas to solve problems in, and gain insights into, other disciplines and other areas of interest such as art and architecture

Measurement
• Analyze precision, accuracy, and approximate error in measurement situations

Data Analysis and Probability
• Find, use, and interpret measures of center and spread, including mean and interquartile range

Problem Solving
• Build new mathematical knowledge through problem solving
• Solve problems that arise in mathematics and in other contexts
• Apply and adapt a variety of appropriate strategies to solve problems
• Monitor and reflect on the process of mathematical problem solving

Reasoning and Proof
• Develop and evaluate mathematical arguments and proofs

Communication
• Communicate their mathematical thinking coherently and clearly to peers, teachers, and others
• Analyze and evaluate the mathematical thinking and strategies of others

Connections
• 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

Representation
• Use representations to model and interpret physical, social, and mathematical phenomena

NRC Science Standards

Inquiry
• Use appropriate tools and techniques to gather, analyze and interpret data
• Develop descriptions, explanations, predictions, and models using evidence
• Think critically and logically to make the relationships between evidence and explanations
• Recognize and analyze alternative explanations and predictions

Common Core Math Standards

6.SP.5 Summarize numerical data sets in relation to their context, such as by:

a. Reporting the number of observations.

b. Describing the nature of the attribute under investigation, including how it was measured and its units of measurement.

• Communicate scientific procedures and explanations
• Use mathematics in all aspects of scientific inquiry

Science as a Human Endeavor

• Scientists are influenced by societal, cultural, and personal beliefs and ways of viewing the world. Science is not separate from society but rather science is a part of society.

Risks and Benefits

• Individuals can use a systematic approach to thinking critically about risks and benefits. Examples include applying probability estimates to risks and comparing them to estimated personal and social benefits.
• Important personal and social decisions are made based on perceptions of benefits and risks.

Abilities of Technological Design

• Identify appropriate problems for technological design.
• Design a solution or product.
• Evaluate completed technological designs or products.
• Communicate the process of technological design.

Understanding About Science and Technology

• Technological designs have constraints. Some constraints are unavoidable, for example, properties of materials, or effects of weather and friction; other constraints limit choices in the design, for example, environmental protection, human safety, and aesthetics.
• Technological solutions have intended benefits and unintended consequences. Some consequences can be predicted, others cannot.
• Creativity, imagination, and a good knowledge base are all required in the work of science and engineering.
## Standards for Mathematical Practices integration with MEAs

<table>
<thead>
<tr>
<th>Mathematical Practice</th>
<th>How it occurs in MEAs</th>
<th>5. Use appropriate tools strategically.</th>
<th>6. Attend to precision.</th>
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<tbody>
<tr>
<td>1. Make sense of problems and persevere in solving them.</td>
<td>As participants work through iterations of their models they continue to gain new insights into ways to use mathematics to develop their models. The structure of MEAs allows for participants to stay engaged and to have sustained problem solving experiences.</td>
<td>Materials are made available for groups as they work on MEAs including graph paper, graphing calculators, computers, applets, dynamic software, spreadsheets, and measuring devices.</td>
<td>Precise communication is essential in MEAs and participants develop the ability to communicate their mathematical understanding through different representations including written, verbal, symbolic, graphical, pictorial, concrete, and realistic.</td>
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<td>2. Reason abstractly and quantitatively</td>
<td>MEAs allow participants to both contextualize, by focusing on the real world context of the situation, and decontextualize by representing a situation symbolically.</td>
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<td>3. Construct viable arguments and critique the reasoning of others.</td>
<td>Throughout MEAs while groups are working and presenting their models.</td>
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<td>4. Model with mathematics.</td>
<td>This is the essential focus of MEAs; for participants to apply the mathematics that they know to solve problems in everyday life, society, or the workplace. This is done through iterative cycles of model construction, evaluation, and revision.</td>
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<td>7. Look for and make use of structure.</td>
<td>Participants in MEAs can use their knowledge of mathematical properties and algebraic expressions to develop their solutions.</td>
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<td>8. Look for and express regularity in repeated reasoning.</td>
<td>As participants develop their models the patterns they notice can assist in their model development.</td>
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Bridge Design-Individual Activity

Read the following information and individually answer the questions that follow.

35W Bridge Collapse

Background material adapted from Mn/Dot Bridge website (http://www.dot.state.mn.us/bridge/)

The Interstate 35W Mississippi River Bridge in Minneapolis collapsed on August 1, 2007. The eight lane bridge was Minnesota’s busiest, carrying 140,000 vehicles a day. This deck steel truss bridge was 1,907 feet long and had 14 spans. It was open to traffic in 1967 and expected to be reconstructed in 2020-2025. The bridge was inspected every two years until 1993; after that it was inspected every year.

Starting in 1997, deficiencies were demonstrated in inspection reports. Mn/Dot attempted to improve the condition of the bridge through bridge span rehabilitations. Furthermore, in 2001 Mn/Dot worked with civil engineers from University of Minnesota to evaluate the fatigue stress within the truss. Following the field tests, the civil engineers recommended that fatigue cracking was not expected to be a problem in the truss but reported that some critical locations of the trusses had high stress and some girders were distorted. The bridge’s last inspection was completed in June 15, 2006. As a result of comprehensive analysis on fatigue and fracture structure recommended supporting the critical 52 truss members.

During the 35W bridge collapse, 13 people were killed and more than 100 injured. The investigations on the collapsed bridge continue. Mn/Dot has investigated every single detail to find what caused the bridge collapse. It has been considered that gusset plates in the center span and the extra weight from construction may have contributed to the tragedy. The gusset plates are steel plates that tie steel beams together on a bridge. These are a very important structural component of truss bridges. However, it should be also considered that gusset plates are not the only structural components in truss bridges; other critical parts of the bridge might have deficiencies. In addition, extra weight may not be a main factor for the bridge collapse since the bridge had less than its usual traffic at the time of the collapse. Half of the lanes were closed for the repair when the bridge failed.
Individually:
- Watch the video of 35 W bridge collapse from http://www.youtube.com/watch?v=osocGiofdvc
- Generate a list of factors you believe are involved in the 35W bridge collapse.

- Generate a list of factors that you need to consider when designing a bridge.

- Once you have finished your individual response, request the memo from Mn/Dot. Read the memo individually and then let your instructor know that you are ready to proceed.
To: White Earth Engineering Team
From: Mn/Dot
Re: Bridge Design

After the I-35 W bridge collapse, Mn/Dot has focused attention on the condition of other bridges in Minnesota. Mn/Dot conducted recent inspections on bridges in the Minnesota and found that there are 1,907 bridges that are structurally deficient. As a result of recent inspections, Mn/Dot shut down another bridge in March 2008. Originally, the bridge was scheduled for replacement in 2015, but Mn/Dot inspectors found critical deficiencies during the inspection. The bridge has a similar design configuration as 35W Bridge and it is located over the Mississippi River in St Cloud. Mn/Dot plans to replace the bridge soon. The new bridge will be located in the same place as the old one. It will carry a highway and run east-west. The length of the bridge will be 144 feet (44 meters). The bridge deck should have two lanes and should also have 5 ft wide sidewalks along both sides of the bridge.

Starting with the St Cloud Bridge, Mn/Dot will replace many of the bridges that have been found to be structurally deficient. Because so many bridges are going to be replaced, Mn/Dot needs a procedure for comparing different type of bridges and choosing the right type of bridge to build across each span. Mn/Dot is asking you to create this procedure. First, your team should decide on the least expensive and safest bridge to replace the St. Cloud Bridge. Pay attention to how you made this decision because we also need you to create a procedure to make the same type of decision in other locations around Minnesota. Mn/Dot will use your procedure to replace the St Cloud Bridge and then other bridges. Please find the enclosed information regarding the types of bridges that Mn/Dot plans to build—truss bridge, arch bridge, suspension bridge, and cable-stayed bridge. In addition to the information about the major types of bridges, Mn/Dot also has provided you two examples of each type of bridge in the U.S. You may need to use this information as a starting point to determine your procedure for selecting the new bridge design. Please respond in a letter to Mn/Dot explaining which bridge is right for the St. Cloud span and why you chose it, and provide them with a method to make the decision of which type of bridge to use to replace any bridge in Minnesota.

Thank you.

Peggy Abrams
Model Eliciting Activity- Part B
Bridge Design- Team Activity

• Read each team member’s individual list of factors that need to be considered when designing a bridge.
• Reread the Memo as a team.
• Write the body of a memo to Peggy Abrams at Mn/Dot that includes:
  o A clear explanation of what type of bridge you decided to build in St Cloud and why you made that decision.
  o A detailed explanation of your team’s general procedure for choosing the best bridge type to build across any span and indicate how Mn/Dot can use this procedure to replace other bridges in Minnesota.