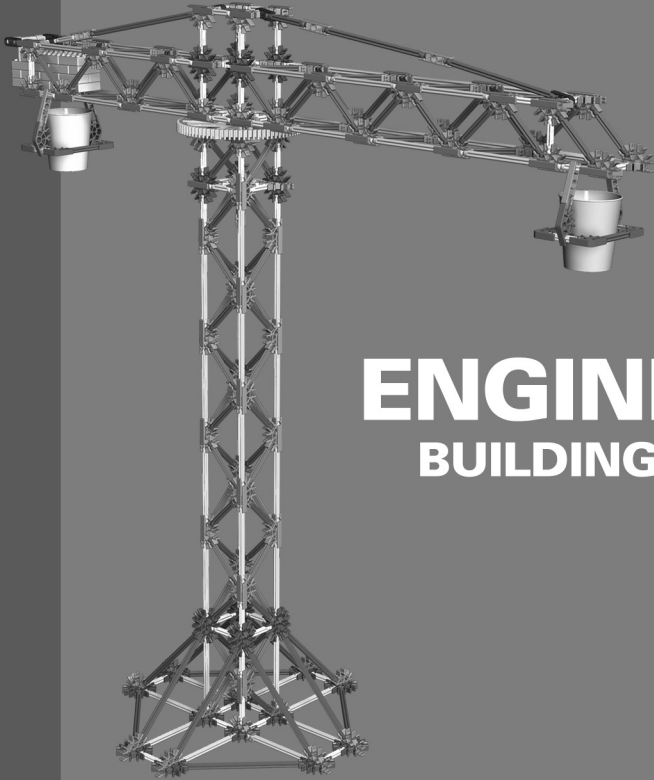


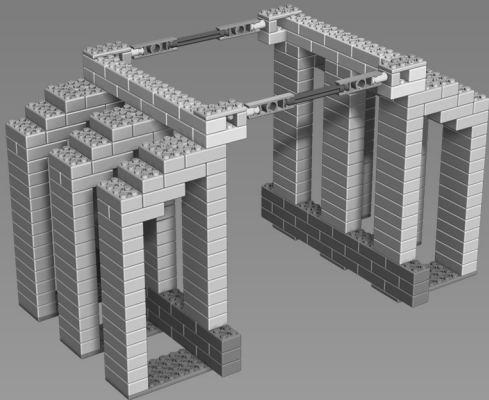
# KNEX<sup>®</sup>

# Education<sup>™</sup>



## TEACHER'S GUIDE<sup>™</sup>

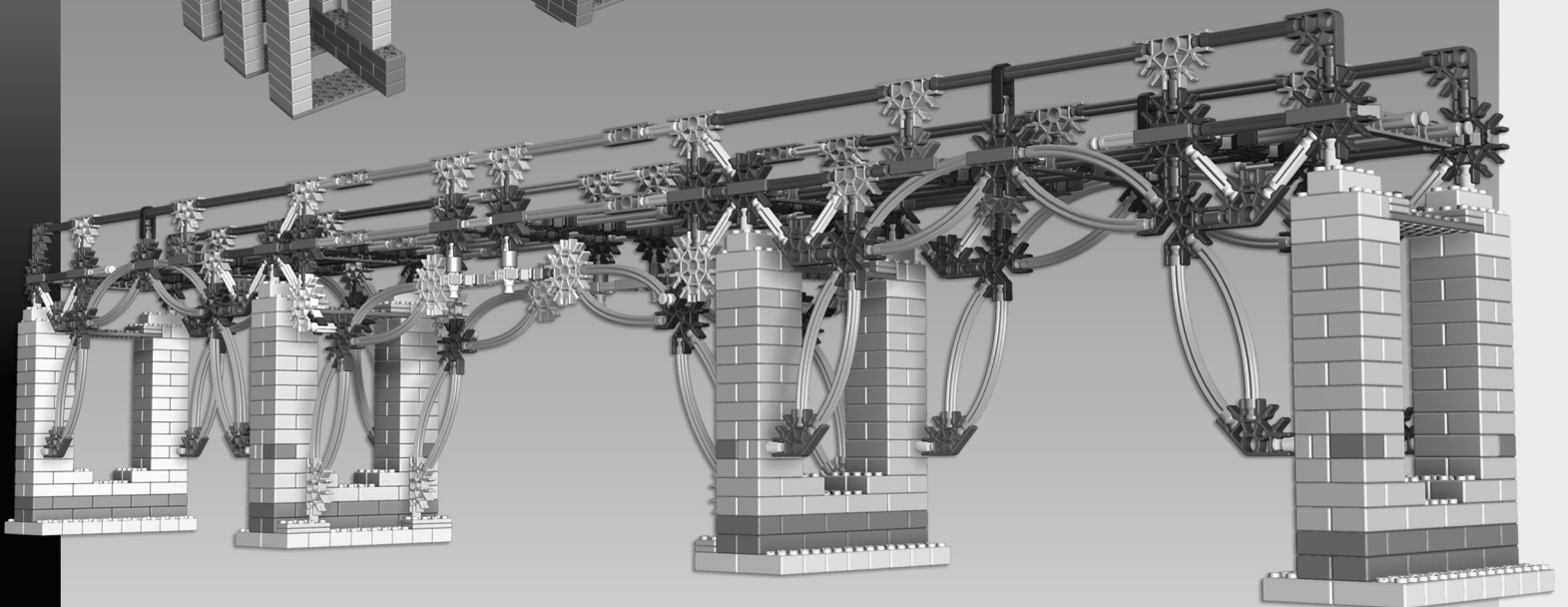
## ENGINEERING MARVELS BUILDINGS, STRUCTURES & MACHINES<sup>™</sup>



**CRANE**



**BRIDGE**



# ENGINEERING MARVELS: Buildings, Structures & Machines

## Teacher's Guide

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P.O. Box 700  
Hatfield, PA 19440-0700

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Email: [abcknex@knex.com](mailto:abcknex@knex.com)  
Phone: 1-888-ABC-KNEX (Toll Free)

Author:  
Bill Metz Ed.D.  
• Presidential Award for Excellence in  
Science Teaching  
• Instructor for the Pennsylvania Governor's  
Institute for Physical Science Educators  
• Co-author of Inquiry by Design: A Collection of  
Design Briefs for Grades 5-9 (2006)  
• Consultant for Full Option Science System (FOSS)

Acknowledgements:  
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### WARNING:

CHOKING HAZARD - Small parts.  
Not for children under 3 years.



### AVERTISSEMENT:

DANGER D'ÉTOUFFEMENT - Pièces de petite taille.  
Ne pas donner aux enfants de moins de 3 ans.



### A Note About Safety

Safety is of primary concern in science and  
technology classrooms. It is recommended that  
you develop a set of rules that governs the safe,  
proper use of K'NEX in your classroom. Safety,  
as it relates to the use of the Rubber Bands  
should be specifically addressed.

### PARTICULAR CAUTIONS:

Students should not overstretch or overwind their  
Rubber Bands. Overstretching and overwinding

can cause the Rubber Band to snap and cause  
personal injury. Any wear and tear or deterioration  
of Rubber Bands should be reported immediately  
to the teacher. Teachers and students should  
inspect Rubber Bands for deterioration before  
each experiment.

**Caution students to keep hands, face, hair and  
clothing away from all moving parts. Never put  
fingers in moving Gears or other moving parts.**

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## Introduction

Architecture can be thought of as a blending of human creativity with the concepts and processes of science. It is an endeavor that has continuously evolved since humans first appeared on Earth. The efforts of engineers, architects, designers and planners can easily be observed in our work spaces, our buildings and other structures, the design of the places in which we live and move, the landscaping that enhances the aesthetics of what we observe and the tools and conveniences we use and experience.

The K'NEX Education **Engineering Marvels: Buildings, Structures and Machines** set has been designed to introduce middle school students to the world of architecture, engineering, science, mathematics and technology through the construction and investigation of a variety of internationally recognized structures. In conjunction with the building of these edifices, students will also be introduced to a number of critical architectural careers including structural and environmental engineering, city/site planning, architectural design and materials science. Furthermore, the role of failure has proven to be an agent of change in these fields; thus the benefits of this process are highlighted as a positive influence in the modification and advancement of subsequent endeavors.

Each of the structures selected for this unit of study can be considered as having historical and/or engineering significance. The design and construction of these structures was, in all cases, unique and “cutting edge” at the time of their development and many of the engineering innovations employed continue to this day. A brief historical sketch has been provided for each of the structures, towers and machines in the form of readers for students to use as they gather background information.

Throughout this module students will be asked to work in collaborative groups as they construct models, modify and investigate structures, conduct related discussions, craft displays and collect pertinent data. Conversely, the processing and interpretation of collected data is generally considered to be an individual effort. The lessons are written to accommodate a variety of learning styles and to provide a number of interdisciplinary connections including design brief challenges, structure related research, model building, mathematical applications, reflective and expository writing, creative design, group deliberations and project presentations.

## INTRODUCTION

## THE NATIONAL SCIENCE EDUCATION STANDARDS<sup>1</sup>

Unifying Concepts and Processes (P.115)	<ul style="list-style-type: none"> <li>• Systems, order, and organization</li> <li>• Evidence, models, and explanation</li> <li>• Change, constancy, and measurement</li> <li>• Form and function</li> </ul>
Science as Inquiry (P. 143) Content Standard A	<ul style="list-style-type: none"> <li>• Abilities necessary to do scientific inquiry</li> <li>• Identify questions that can be answered through scientific investigations</li> <li>• Design and conduct a scientific investigation</li> <li>• Use appropriate tools and techniques to gather, analyze, and interpret data</li> <li>• Develop descriptions, explanations, predictions, and models, using evidence</li> <li>• Think critically and logically to make the relationship between evidence and explanations</li> <li>• Recognize and analyze alternative explanations and predictions</li> <li>• Communicate scientific procedures and explanations</li> <li>• Use mathematics in all aspects of scientific inquiry</li> <li>• Understandings about scientific inquiry</li> </ul>
Physical Science (P. 149) Content Standard B	<ul style="list-style-type: none"> <li>• Properties and changes of properties in matter</li> <li>• Motions and forces</li> <li>• Transfer of energy</li> </ul>
Science and Technology Content Standard E (P. 161)	<ul style="list-style-type: none"> <li>• Abilities of technological design</li> <li>• Identifying appropriate problems for technological design</li> <li>• Design a solution or product</li> <li>• Implement a proposed design</li> <li>• Evaluate completed technological designs or products</li> <li>• Communicate the process of technological design</li> <li>• Understandings about science and technology</li> </ul>
Science in Personal and Social Perspectives Content Standard F (P. 166)	<ul style="list-style-type: none"> <li>• Populations, resources and environments</li> <li>• Natural Hazards</li> <li>• Risks and benefits</li> <li>• Science and technology in society</li> </ul>
History of Science Content Standard G (P. 170)	<ul style="list-style-type: none"> <li>• Science as a human endeavor</li> <li>• Nature of science</li> <li>• History of science</li> </ul>

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<sup>1</sup> National Research Council. 1995. National Science Education Standards. Washington, DC: National Academies Press.



# Standards



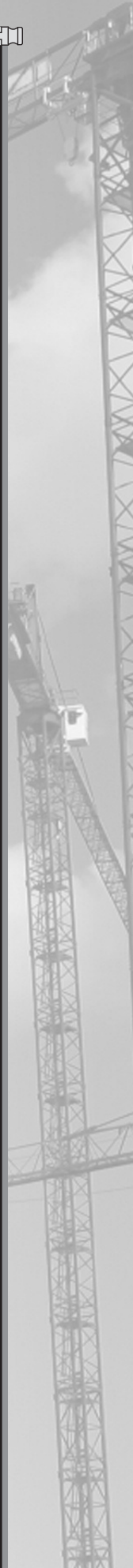
## ALIGNMENT WITH NATIONAL STANDARDS

### INTERNATIONAL TECHNOLOGY EDUCATION ASSOCIATION STANDARDS<sup>1</sup>

Nature of Technology	Students will develop an understanding of: <ul style="list-style-type: none"> <li>• the scope of technology</li> <li>• the core concepts of technology</li> <li>• the relationships among technologies and the connections between technology and other fields of study</li> </ul>
Design	Students will develop an understanding of: <ul style="list-style-type: none"> <li>• the attributes of design</li> <li>• engineering design</li> <li>• the role of trouble shooting, research and development, invention and innovation and experimentation in problem solving</li> </ul>
The Designed World	Students will develop and understanding of and be able to select and use: <ul style="list-style-type: none"> <li>• medical technologies</li> <li>• agricultural and related biotechnologies</li> <li>• energy and power technologies</li> <li>• information and communication technologies</li> <li>• transportation technologies</li> <li>• manufacturing technologies</li> <li>• manufacturing technologies</li> <li>• construction technologies</li> </ul>
Technology and Society	Students will develop an understanding of the: <ul style="list-style-type: none"> <li>• cultural, social, economic and political effects of technology</li> <li>• effects of technology on the environment</li> <li>• role of society in the development and use of technology</li> <li>• influence of technology on history</li> </ul>

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<sup>1</sup> International Technology Education Association. 2000. Standards for Technological Literacy: Content for the Study of Technology. Reston, VA: International Technology Education Association.



## TEACHER'S GUIDE:

This unit has been developed to introduce students to a number of unique architectural structures, many of which are considered engineering benchmarks. The **Engineering Marvels: Buildings, Structures and Machines** set has been designed to allow two (2) groups of students to build models at the same time. To that end, two (2) separate building instruction booklets are included in this set to guide students in building the featured models. Use the matrix below to identify different options for building 2 models at once (one for each group of students).

	BUILDING ACTIVITY	
	Group A - Using Instruction Booklet #1	Group B - Using Instruction Booklet #2
<b>Option #1</b>	Big Ben	Big Ben
<b>Option #2</b>	CN Tower	CN Tower
<b>Option #3</b>	Space Needle	Space Needle
<b>Option #4</b>	Eiffel Tower	Eiffel Tower
<b>Option #5</b>	Arc de Triomphe	Windmill
<b>Option #6</b>	Flying Buttress	Crane
<b>Option #7</b>	Iron Bridge (dual group activity)	

The set also contains a comprehensive Teacher's Guide with eight hands-on, inquiry-based lessons that include a historical background of each building, structure or machine the students build, as well as descriptions of occupations associated with the development of modern structures.

Each lesson identifies the objectives of the activity, lists the materials needed to carry out the investigation, and provides an overall time allotment as well as approximate time frames for each lesson segment. It should be noted that the actual time required to complete any investigation, will vary based on a number of variables such as class size, amount of material, the experience and interest of the students.

Lessons are accompanied by one or more Student Response Sheets that provide directions and space for recording observations, responding to questions and crafting additional investigations. Teachers should reproduce the Student Response Sheets for their classes. Challenge questions are also provided in the form of Design Briefs. These extension investigations encourage students to apply the new knowledge and learned concepts in novel settings. These design briefs can be used as enrichment activities as well as for evaluation purposes.

There are also research opportunities for students throughout this unit of study. In some cases the research is needed to complete an assignment while in other instances the research is suggested as an extension or optional activity to enrich student understanding.



## Teacher Notes

### LESSON STRUCTURE:

The lessons in this Teacher's Guide have been crafted following the **5E Instructional Model**. This teaching strategy begins with an **ENGAGEMENT**, wherein the teacher creates interest and elicits responses from the students through thought provoking questions, interactive demonstrations and open discussions. In the second phase, the **EXPLORATION**, students are encouraged to work together building the models, designing potential solutions to problems and crafting responses to initial questions. Students then **EXPLAIN** their observations, interpretations, and conceptual understandings in their own words. The teacher plays two major roles during this segment. Initially, teachers serve as a moderator and facilitator of discussion allowing and encouraging the students to share and explain what they did, what they observed and what they think it means. The secondary role teachers perform during this segment is as a provider of new information including vocabulary words but only following a generalizing experience of some kind.

In the next phase, the students are subsequently expected to apply the concepts, skills and understandings gained in the first three parts as they progress through the **ELABORATION** segment. It is also expected that students will begin to appropriately apply the formal labels, understand definitions, craft reflective explanations, and possibly modify the models and designs to accommodate a different or enhanced function. In the final phase of the 5E Instructional Model, the **EVALUATION**, students are expected to further apply the new concepts as they address real life applications and design brief challenges.

### THE DESIGN BRIEF:

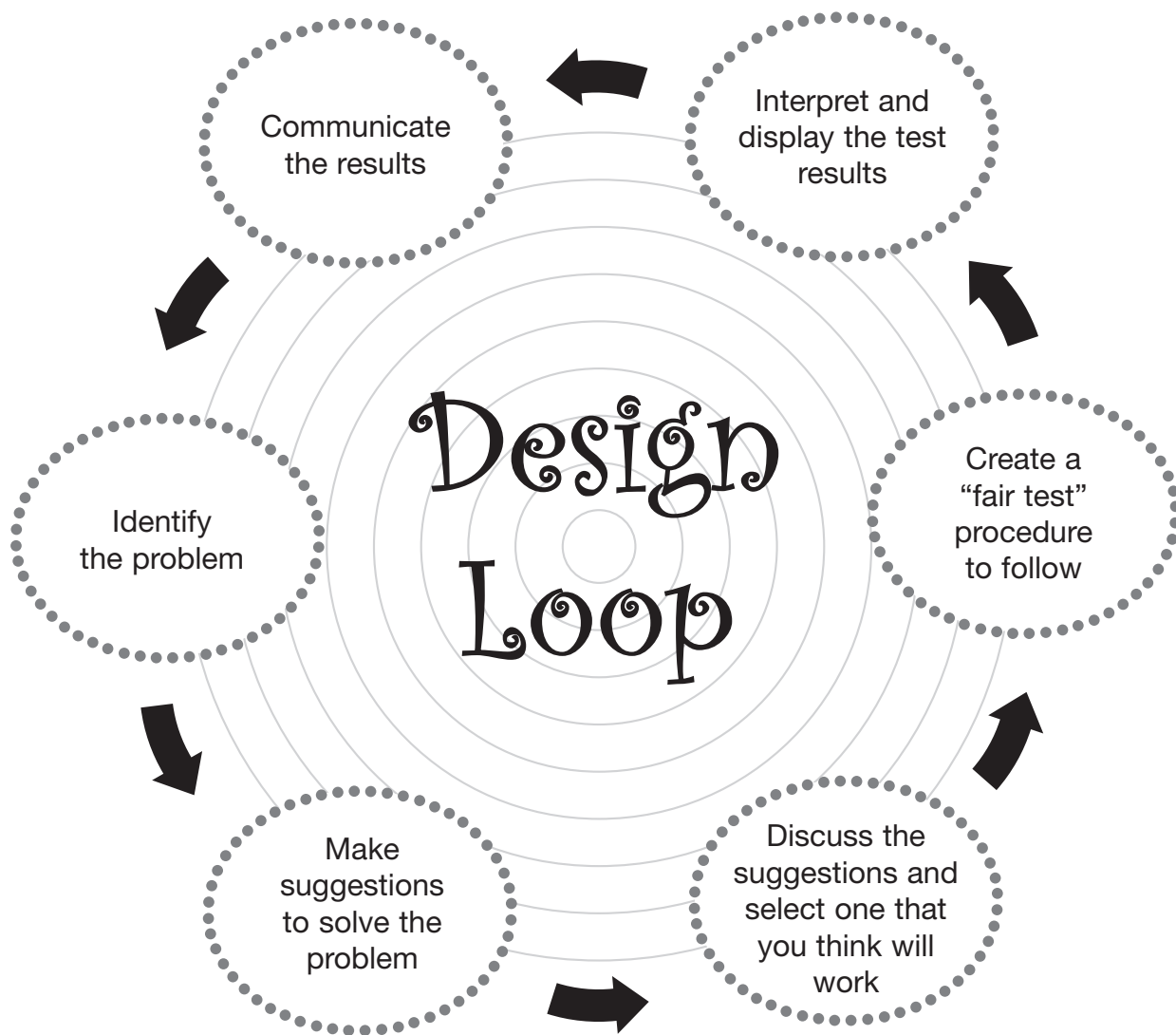
Design briefs are a blend of technology education with the content and processes of science. These open-ended invitations to learn exemplify scientific inquiry, wherein a problem is identified, investigated and analyzed. During this process, students research existing ideas, craft new thoughts, select and test possible solutions, and analyze data. Students are also expected to evaluate their data-supported outcomes and communicate their results in meaningful ways.

Design briefs generally begin with the **Context**, a statement that provides a broad-based perspective of an issue. This is followed by the **Scenario**, a description of a plausible, real-life situation reflective of the contextual statement. The third component in the design brief is the **Challenge**, wherein the task is described. The remaining sections in this process are the **Limitations** or constraints under which the problem must be resolved, and the **Rules** that are used for judging the quality or efficiency of the results.



**DESIGN LOOP:**

The Design Loop is the basic strategy used in solving problems. Ideas can originate from anywhere as the circle can be entered from any location. As the students pursue designing, constructing and testing the various architectural structures in this unit they may also find that changes or modifications may be necessary. The students should also understand that the process of “backtracking” is common and, in some cases an essential practice in problem solving.



TEACHER NOTES



## Teacher Notes

### INSTRUCTIONAL STRATEGIES:

The best way to administer the investigations provided in this Teacher's Guide will be determined by the teacher, the nature of their classes, their curriculum goals, and national, state, and local standards. As teachers review their science and technology standards they may gain additional insight into how to further enrich the experiences provided in this set with the addition of other classroom supplies, associated non-fiction reading material, logical connections with other areas of the curriculum, student generated queries, and internet applications, to name a few. The following suggestions may also be helpful:

- If students keep a record of their observations and investigations in a science journal, use this as a means of formative assessment. Alternatively, have students keep their Student Response Sheets in a designated lab folder for referral, assessment, and note keeping purposes.
- If teachers would rather have students record their observations and data in individual science journals, the Student Response Sheets can be omitted. The teacher can use the questions found on these sheets as a starting point for guided inquiry. Using this approach, the teacher can then modify the investigations to better suit individual classroom or curriculum needs.
- Laminate model building instructions. This will ensure the paper versions survive from class to class and from year to year.
- Practice building the proposed model in advance. Experience with each model allows the teacher to troubleshoot those areas where students are most likely to encounter difficulty. Resist the urge to help students through difficult building challenges too quickly. Students should work through these challenges as a group and in the process they will enhance their problem solving skills.
- Provide containers. It may be helpful to provide student groups with some means of confining the pieces to the desktop. Cafeteria trays or boxes with low sides, such as the type used to transport soda cans, allow the students to have building materials on the desktop without worrying about pieces rolling away and getting lost. Similarly, transparent or translucent cups or beakers are a great way to keep track of the smallest pieces.
- Establish safety guidelines. Take time to direct the students' attention to the 'Building with K'NEX' section of the Building Instructions booklet on Page 3 to review the proper use of K'NEX pieces. Review safety procedures for the care and use of manipulatives in the classroom with your students.
- Experience First! Engage the students in building and explaining models early on in each lesson. These preliminary investigations provide students with a generalized frame of reference that increases their understanding of terms and concepts. The introduction of vocabulary should follow the students' experience with materials whenever possible. Word Charts or Word Walls containing the vocabulary words, definitions, and student interpretations should be on display in the room as a visual reference for all students throughout the unit of study.
- Trade-offs. Throughout this unit there are references to the idea of trade-offs. As students investigate they should be asked to determine what is being lost and what is being gained as modifications are made.
- Encourage students to work collaboratively. Suggest that students use their notes and discuss questions and ideas within their groups that are raised during the investigations.
- Review Often. Capitalizing on prior experiences is a valuable technique that helps build the students' understanding of new concepts and relationships. Do not underestimate the effectiveness and the necessity of student interaction. The adage: "He who does the talking does the learning" is an incredibly powerful method of instruction, but requires teachers to provide the time and the atmosphere for this to happen.

## EXTENSION AND OPTIONAL ACTIVITIES

There are a several extension opportunities for students to ‘go beyond’ the essential lessons. Teachers should be aware that these challenges could be approached in a number of ways and that students may need additional time and resources to pursue these investigations. Every attempt has been made to move from standard knowledge-based questioning to investigation, experimentation, and inquiry. The questions and requirements associated with each lesson are designed to help students develop higher order thinking skills through collecting, processing, interpreting, applying and communicating data via a variety of venues.

### SCIENCE NOTEBOOKS:

As students engage in the process of pursuing the challenges presented in this unit of study, they will be expected to record and interpret their observations, thoughts, data and illustrations. It is anticipated that they will also reprocess this information in drawing conclusions and crafting additional queries for further investigation.

For the students, maintaining a science notebook provides a continuous record of events that can also be used as supportive evidence, self assessment and research. Notebooks also provide a logical place for the students to organize information in ways that makes sense to them. These student generated documents provide teachers with a window into how students are processing and interpreting information. The notebooks are a formative assessment treasure trove that permits teachers to peruse students’ understandings and misconceptions.

### TEAM RESPONSIBILITIES VS. INDIVIDUAL TASKS:

Collaborative work is an accepted and appropriate procedure as it fosters reliance on others and increases the importance of individual contributions within a group setting. In addition, it is a necessary format considering time and material constraints; however, there is a question about its appropriateness in regard to assessment. Toward this end, it is suggested that all students receive a grade for what they do in a laboratory setting. This rating should be individualized and reflect the expectations established prior to the beginning of the investigation. For example, if you expect the students to collect and process data during the experiment, they should be made aware of this, and you should be focused on that respective process during the lesson.

Collaborative groups are generally a more efficient way to design, construct and collect data but, it should be the responsibility of each student to process and interpret that data. Throughout this guide you will find headings that reflect this belief. Collaborative group work is entitled “**As a Team**” while individual tasks are labeled “**On Your Own**.” Students should be introduced to this procedure and reminded about the difference in “ownership.” It is further suggested that when students reach the point in the lesson when they are to be “On Their Own,” collaborative groups should be disbanded. These individual sections could also be assigned as homework.

### FAIR TESTS:

Throughout this K’NEX Education Teacher’s Guide, the term “**fair test**” has been used in reference to a student structured investigation. Children have an innate sense of fairness and tend to understand “fair test” better than the traditional concept of a “controlled experiment.” If your students have not had experience in designing “fair tests” then it is suggested that you take a few minutes to walk them through this process. In sum, a “fair test” is an experiment where all factors or variables are kept the same except the one that is to be tested or changed. A Fair Test Overview is provided in the first lesson of this module with suggestions regarding its use.



## Teacher Notes

The intent of this strategy is essentially a formative assessment for the teacher as they seek to determine how students grapple with the concept of designing a “fair test” procedure as well as an instructional opportunity to teach this process. If you feel that your students will be able to handle this process, by all means, allow them to proceed. On the other hand, if you believe they may benefit from direct instruction, make a transparency of the “**Fair Test Overview**” and walk the students through the process. It is also suggested that this transparency, or a permanent chart copy, be on display throughout this lesson as a reference. As students design their procedures it is important that their progress be observed and guided. In addition, prior to the students performing their tests it is suggested that they share what they have designed so that other teams will have the opportunity to revisit the “fair test” process, reflect on what has been shared as well as on what they have crafted.

***As students work their way through the investigations in this manual they will be expected to assume more of the responsibility for crafting the components associated with “fair test” investigations.***

### **TECHNICAL/SCALE DRAWINGS:**

For the purposes of these investigations, scale/technical drawings are defined as accurate two-dimensional representations of objects. These illustrations should include: color, dimensions, labels when appropriate, and multiple views (top, front, and side) if necessary for clarity. Additional features include a title, name of architect, and drawing key that includes color code and scale. You can vary the details from the list above to address time constraints and the specific goals of your curriculum.

### **GRAPHING CONVENTIONS:**

Teaching students a consistent way of crafting data displays is essential for helping to assure the accurate and uniform processing and interpretation of data. The initial experiences in this manual provide the formats and the labels for the graphs. As the students progress they will find that more of the responsibility for creating these communication tools is placed on their shoulders. It is strongly suggested that students maintain an ongoing science notebook or journal of some kind so as to have a continuous record for reflection and reference.

While students could use the internet or computer programs like Excel to generate graphs, it is suggested that they also learn how to create graphs without this technology, since the necessary hardware may not be readily available, or for that matter, necessary, in some situations.

The two basic graphs that are most widely used are the line graph and the bar graph and each is appropriate for a given type of data. If the data is discrete or categorical such as the days of the week, kind of tree, brand of cereal, eye color, and so on, the bar graph should be used. If the data is continuous and the measurements involve a standard scale, the most appropriate graph is the line graph.

Following are graphing conventions that students may find helpful. These steps should prove a valuable reference until said time when students have demonstrated their competence with the graphing process.

### **GRAPHING SUGGESTIONS:**

- Every graph should have a heading that identifies the person or persons that crafted the display. The date and other identifying information should also be included.
- Every graph should have a title that briefly describes the investigation.
- The horizontal axis should first be labeled with the letter **X** and the vertical axis with a **Y**.



- Both axes should be titled and these descriptions should be the same as the titles on the data table.
- Data for the **independent variable**, the variable that is controlled or changed, always goes on the **X** axis.
- Data for the dependent variable is placed on the **Y** axis.
- The axes should be numbered so that the investigative data will fit on the graph.
- Numbering the axes lines is a matter of finding a reasonable interval for each axis to accommodate the collected data. Begin by finding the difference between the smallest and largest value for one of the variables, then estimate how this difference can be evenly distributed along the axis.
- The graph should be made large enough to fill the available space. The size of a graph can be changed by increasing or decreasing the numerical increment on the axes. For example, if an axis is numbered by 10's and the graph is too small, changing the numbering to 5's will stretch the graph out to a larger size.
- After the data is plotted on the graph, a line of "best fit" will need to be drawn. The data points are usually not connected in a dot to dot fashion. Draw the best straight line or smooth curved line that goes through as many points as possible.

## ASSESSMENTS:

The role of assessment in the **Engineering Marvels: Building, Structures and Machines** set is designed to determine the students' level of understanding prior to instruction and the level of growth following instruction. There are several ways in which this is structured including:

- **Formative Assessments** – This form of evaluation is focused on determining the students' level of understanding prior to instruction or at anytime during instruction. In most cases this assessment does not result in a grade of any type but provides teachers with feedback regarding the direction and the differentiation of instruction.
- **Teacher Observation** - It is suggested that a continuous record of students be maintained via teacher observations. It is unreasonable to assume that notes regarding each and every student be taken each time they are involved in a project of some kind. It is, however, reasonable to record some anecdotal notes about six or seven students and, over time, the observations will add up.
- **Student Response Sheets** - These recording sheets have been crafted to allow students a sequential and varied way to process information.
- **Student Writing Assignments** - The process of reflective writing cannot be underestimated in the thinking-learning process, and there are multiple opportunities in this module for students to apply and polish this important communication skill.
- **Performance Assessments** - Creating situations wherein the students have to demonstrate their understanding of concepts and processes through some type of performance is unquestionably an upper level assessment.
- **Laboratory Grades** - While these assessments do not appear in any lessons they become the responsibility of each teacher every time the students are involved in a hands-on, minds-on investigation. Teachers are strongly urged to grasp these opportunities to issue grades (letter, percentage, points, and so on) to students for what they do during these activities. Whatever the scoring system it should be organized, easy to administer and no secret to the students. It is suggested that your expectations for the laboratory activity appear on the board to serve as a management rubric for the students.



## Teacher Notes

- Student and Project Presentations - There are a number of presentation opportunities for students in this module. Make certain that students have the scoring rubrics (included in this guide) and comprehend them when the investigation is assigned.
- Appropriately designed and controlled “Fair Tests” solutions - Creating “Fair Tests” is an upper level undertaking that teachers should encourage in their students. This endeavor employs and promotes the integrated process skills of identifying and controlling variables, formulating hypotheses, inferring, processing and interpreting data, and experimenting.
- Reasonable interpretations and summations of collected data – While there are multiple routes to finding the solution to a problem there is truly only one way to answer and that is with the appropriate use of supportive data. Teachers should be open and accepting of the unique ways in which students go about resolving dilemmas while at the same time demanding data based decisions and interpretations.

### GLOSSARY OF TERMS

**Independent Variable:** The independent variable is that factor which is manipulated, changed or actively controlled by someone during an investigation. According to graphing conventions the independent variable is always placed on the X axis.

**Dependent Variable:** The dependent variable is that factor that changes in response to purposive changes in the independent variable. The dependent variable is sometimes referred to as the responding variable and, by convention, is always recorded on the Y axis of a graph.

**Constants:** When conducting a “fair test” investigation students should become familiar identifying the variables that could affect the results or outcome. Aside from the variable selected as the independent factor and the dependent variable that will be measured, these that remain are considered “constant” and need to be kept the same throughout the investigation. Should these variables not be held constant then the results of an investigation are suspect.

**Mechanical Advantage:** Mechanical advantage is generally associated with the use of tools and simple and complex machines. In sum, the mechanical advantage of a simple machine reflects how many times the machine multiplies a force that is applied to that machine.

**Serendipity:** Serendipity can be defined as a fortunate accident. It happens when someone discovers something when looking for something else. It also refers to the chance occurrence of events, for example, in the case of Shropshire, England, where all of the raw materials for the iron industry were readily available.

**Harmonics:** There are two types of vibrations that are associated with most materials, free and forced. The free vibrations occur as a result of the characteristics in the design. Forced vibrations, on the other hand, are those that occur from outside influences such as human intervention, wind and/or other natural forces (see Failures, Tacoma Narrows Bridge collapse). If the free and the forced influences coincide the vibrations can become magnified, or are in harmony, and the object can be damaged.

**INTERNET RESOURCES**

(These URLs were operating, informative, and supportive of the content presented in this Teacher's Guide on September 12, 2008 when this guide was prepared. Please review these sites prior to using them with your students.)

**Engineering Disasters and Failures:**

- <http://www.history.com>
- <http://www.matscieng.sunysb.edu/disaster/>
- <http://www.library.ubc.ca/scieng/engineeringfailure/EngFailures.htm>

**Structures****Iron Bridge:**

- [http://en.wikipedia.org/wiki/The\\_Iron\\_Bridge](http://en.wikipedia.org/wiki/The_Iron_Bridge)
- [http://www.greatbuildings.com/buildings/Iron\\_Bridge\\_at\\_Coalbrookdale.html](http://www.greatbuildings.com/buildings/Iron_Bridge_at_Coalbrookdale.html)
- <http://www.worldheritagesite.org/sites/ironbridgegorge.html>

**Arch de Triomphe:**

- <http://www.discoverfrance.net/France/Paris/Monuments-Paris/Arc-CDG.shtml>
- <http://www.paris.org/Monuments/Carrousel/>
- <http://www.aviewoncities.com/paris/arcdetriomphe.htm>
- <http://www.bluffton.edu/~sullivanm/arctriomphe/arc.html>

**The Eiffel Tower:**

- <http://www.tour-eiffel.fr/teiffel/uk/>
- <http://www.paris.org/Monuments/Eiffel/>
- <http://www.discoverfrance.net/France/Paris/Monuments-Paris/Eiffel.shtml>

**Tower Cranes:**

- <http://science.howstuffworks.com/tower-crane.htm>
- [http://www.pcap.com/strat\\_cr.htm](http://www.pcap.com/strat_cr.htm)
- [http://en.wikipedia.org/wiki/Crane\\_\(machine\)](http://en.wikipedia.org/wiki/Crane_(machine))

**Big Ben:**

- [http://en.wikipedia.org/wiki/Big\\_Ben](http://en.wikipedia.org/wiki/Big_Ben)
- <http://www.aboutbritain.com/BigBen.htm>
- <http://www.whitechapelbellfoundry.co.uk/bigben.htm>
- [http://www.travellondon.com/templates/attractions/gallery\\_bigben.html](http://www.travellondon.com/templates/attractions/gallery_bigben.html)

**The Seattle Space Needle:**

- [http://en.wikipedia.org/wiki/Space\\_Needle](http://en.wikipedia.org/wiki/Space_Needle)
- [http://www.historylink.org/essays/output.cfm?file\\_id=1424](http://www.historylink.org/essays/output.cfm?file_id=1424)
- <http://architecture.about.com/library/blspaceneedle.htm>

**The CN Tower**

- [http://en.wikipedia.org/wiki/CN\\_Tower](http://en.wikipedia.org/wiki/CN_Tower)
- <http://www.emporis.com/en/wm/bu/?id=cntower-toronto-canada>
- <http://skyscraperpage.com/cities/?buildingID=21>
- <http://www.infoplease.com/ipa/A0886190.html>



## Teacher Notes

### The Flying Buttress

- [http://en.wikipedia.org/wiki/Flying\\_buttress](http://en.wikipedia.org/wiki/Flying_buttress)
- <http://www.pitt.edu/~medart/menuglossary/flier.htm>
- <http://www.wisegeek.com/what-is-a-flying-buttress.htm>
- [http://tudorhistory.org/glossaries/f/flying\\_buttress.html](http://tudorhistory.org/glossaries/f/flying_buttress.html)
- <http://www.historyforkids.org/learn/architecture/flyingbuttress.htm>

### The Windmill

- <http://en.wikipedia.org/wiki/Windmill>
- <http://www.greenwindmill.com/>
- <http://servercc.oakton.edu/~wittman/mills/types.htm>

### Occupations

#### Architect:

- <http://en.wikipedia.org/wiki/Architect>
- <http://www.bls.gov/K12/build04.htm>
- <http://www.calmis.ca.gov/file/occguide/architec.htm>

#### Structural Engineer

- [http://en.wikipedia.org/wiki/Structural\\_engineering](http://en.wikipedia.org/wiki/Structural_engineering)

#### City/Site Planner

- <http://www.bls.gov/oco/ocos057.htm>
- <http://www.princetonreview.com/cte/profiles/dayinlife.asp?careerid=162>
- [http://en.wikipedia.org/wiki/Urban\\_planning](http://en.wikipedia.org/wiki/Urban_planning)
- <http://www.planning.org/KidsAndCommunity/whatisplanning/default.htm>

#### Environmental Engineer

- <http://www.bls.gov/oco/ocos027.htm>
- [http://en.wikipedia.org/wiki/Environmental\\_engineering](http://en.wikipedia.org/wiki/Environmental_engineering)

#### Materials Scientist

- [http://en.wikipedia.org/wiki/Materials\\_science](http://en.wikipedia.org/wiki/Materials_science)
- <http://www.bls.gov/oco/ocos049.htm>
- <http://www.strangematterexhibit.com/whatis.html>



# BIG BEN

## Lesson 1

### Objectives:

Students will be able to:

- Work effectively in collaborative teams
- Identify variables that might affect a moving system
- Design and conduct a “fair test” investigation
- Design and/or construct a mechanical device according to specific criteria

### Models:

- Two groups can build Big Ben models simultaneously

### Materials:

- K’NEX Engineering Marvels: Buildings, Structures and Machines Set
- Copies of the **History of Towers** historical perspectives reader
- Different types of string (twine, fishing line, etc.)
- A variety of masses (fishing weights or large metal washers)
- Graph paper
- Copies of:
  - \* **Student Response Sheet #1**
  - \* **Student Response Sheet #2**
  - \* **“Fair Test Overview”** transparency (To be made from a master by the teacher if needed)



### ENGAGE:

1. Prior to the beginning of the class period, construct a large demonstration pendulum. Attach a string to the ceiling or door jamb. Attach a pendulum bob (large washer, a fishing weight or similar object) to the free end of the string.
2. Have the students observe and record the motion of the pendulum as you release it and let it swing back and forth. How many swings (periods) does it complete in one minute (Students can count the periods in 15 seconds and multiply by four). Then, ask the class what factors they think might affect the number of swings the pendulum completes in one minute. (The period of a pendulum is essentially the time required to complete a swing and return to the release point.)
3. Record all student responses on chart paper to later serve as variables which will be investigated in student created “fair test” investigations. Students might suggest such factors as:

String length	Amount of mass	Shape of mass
Type of string	Drop height	
4. Introduce the concept of a variable if your students are not yet familiar with the term.

Time Frame approximately 15 minutes



**EXPLORE:**

Challenge the students to select one of the pendulum variables to investigate. Remind them that they must design a “fair test” investigation to determine if the factor they selected makes a difference in the number of periods the pendulum completes in one minute. Students will need to conduct multiple trials, compute averages, create a data display to communicate their findings and interpret the results to others.

If your students have not previously conducted their own “fair test” investigations it is suggested that some time be set aside to review the **Fair Test Overview**. For additional guidance, students will be given further support via the explicit format of **Student Response Sheet #1**.

Time Frame approximately 20 minutes

**IF NECESSARY:**

This investigation is intended to serve as both a formative assessment for the teacher as well as an instructional opportunity to teach the process of designing a “fair test.” If you feel that your students will be able to handle this process, allow them to proceed. If you believe they may benefit from direct instruction, make a transparency of the **Fair Test Overview** and walk the students through the process. It is also suggested that this transparency be on display throughout this lesson as a reference. As students design their procedures, it is important that their progress be observed and guided. In addition, prior to the students performing their tests, it is suggested that they share what they have designed so that other teams will have the opportunity to revisit the “fair test” process and reflect on what they have crafted.

Time Frame approximately 45 minutes

**EXPLAIN:**

After the student groups have completed their fair test investigations, ask them to share their summarized results with others. If discrepancies exist, such as claims that more than just the string length made a difference in the period of the pendulum, have the students resolve these through further, more extensive, investigation.

Time Frame approximately 25 minutes

**ELABORATE:**

1. Distribute the Engineering Marvels set and have the student teams construct the model of Big Ben. Once the models are complete, ask the students to read **The History of Towers: Big Ben** to discover how the four clocks of this English icon are powered.

Time frame approximately 45 minutes



2. The students will discover that Big Ben is a pendulum powered timepiece. Instruct students to return to the pendulums they used earlier to see if they can determine if there is a discernable pattern between the string length and the number of periods in one minute. Ask the students to select and collect data for five different pendulum strings between 20 cm and 120 cm in length. Remind the students that they will also need to create a data display and a graph to communicate their findings. Finally, require the students to “Make Up A Rule” about string length and their pendulum’s period that summarizes what they have discovered. Using their rule, they should generate a prediction and test for the number of periods a pendulum will complete in one minute using an untested string length. Some direction and prompts are included in **Student Response Sheet # 2** for this activity.

Time frame approximately two 45 minute periods.



### EVALUATE:

In this phase, students are asked to complete the **Timing is Everything** design brief which challenges them to create a timing device. Depending on time constraints and the availability of materials for students to use during this activity, you may choose to have students design, draw and present their timing device rather than design, draw, construct, troubleshoot, and present a machine on their own. A project assessment rubric has been provided to give guidance to the students as they plan their projects. Extension activities have also been provided that will allow students to extend their explorations.

Time Frame approximately three 45 minute periods





# Student Response Sheet

# 1

Name: \_\_\_\_\_

Date: \_\_\_\_\_

What factor has your team decided to test? (variable)

What factors are going to stay the same with each test? (constants)

Why do you think it is important to change only one variable while keeping all the others constant with each test?

What kind of data do you plan to collect and how long will the test last?

How will you collect that data?

How do you plan to display that data?

In what ways could you communicate that data to others?

Be sure to use the data when you summarize your results.

Further questions:

**BIG BEN**

# Student Response Sheet

## 2

Name: \_\_\_\_\_

Date: \_\_\_\_\_



**Question:** Is there a pattern between the string length of a pendulum and the number of periods that pendulum will complete in one minute?

What five string lengths have you selected to test? (All choices should be between 20cm and 120 cm in length.)

How many trials will you conduct?

Design and describe a data display for your collected data.

Graph your data to communicate your results.

Make up a rule that summarizes your results.

Select two lengths of string that were not tested earlier. Using your graph, predict how many periods each of these two new pendulum strings will complete in one minute. Make your predictions and then test them to verify your predictions.

**BIG  
BEN**



# Fair Test Overview

A “fair test” investigation is one in which all factors or variables are kept the same except one. That is how we know that the results can be attributed to **that** particular variable. For this reason, it is also called a controlled experiment. Here is an example:

A team of students wanted to find out if the salt solution spread on the roads during the winter time affected grass plants that grew along side the road. The team decided to design and conduct a fair test to see if they could answer their question.

**What factor (variable) has your team decided to test?** Our team will test the concentration of salt solutions on the growth of grass plants. We will make six different salt concentrations with water ranging from zero salt to very concentrated.

**What factors (variables) are you going to keep the same with each test?** We will keep the size and types of grass plants the same (we’ll use identical pieces of sod). Each piece of sod will be watered with the same amount of water, at the same time. The sod pieces will be kept in the same area under the same exact lighting and temperature conditions.

**Why do you think it’s important to change only one variable while keeping all the other variables the same with each test?** It is important to keep everything the same except the one variable tested because, if we don’t, how will we know if our tested variable really made a difference?

**What kind of data do you plan to collect and how long will the test last?** We will measure the growth of the grass plants as well as note any color changes. Our test will last three weeks.

**How will you collect that data?** The data will be collected using a metric tape and a color chart that shows gradient shades of green and yellow

**How do you plan to display that data?** We will create a data chart that shows the different salt concentrations and the measurements and color observations that we make.

**In what ways could you communicate that data to others?** We could make a color graph to show the results of what happened to our grass plots over a three week period.

## **AFTER RESULTS ARE RECORDED**

**Be sure to use the results when you summarize your results.** Our results show that grass watered with plain water grows better than grass watered with salt water. The dilute salt water did not change the color of the plants very much but it did slow down the growth of the grass. Grass watered with stronger concentrations of salt water died within the first week.

**Further Questions:** We wondered if plants that were watered only once with salty water could be revived. The reason we wonder about this is because the plants along the road do not get a steady diet of salt water during the winter. We also wondered about the effects of this procedure on other plants.

# Timing is Everything Design Brief



## **The Context:**

Time is very often an essential part of life.

## **The Scenario:**

The Bonanza Bagel Company is in deep trouble. During a late night thunderstorm electrical power for the entire neighborhood was knocked out. The bagel cookers were fine because they were gas powered; but the bakers have no way of knowing how long to cook the bagels because the clocks are not working and they may not wear watches because of sanitary regulations.

## **The Challenge:**

As bagel baker trainees, your team has taken on the task of building a timing device that will accurately time a period of 60 seconds to help the bakery during future power losses. Your project will be divided into a number of segments: research, planning, design, construction, testing, modifications and presentation. (If your group will not be building an actual timing device, your project will include the following segments; research, planning, design and presentation.)

## **The Limitations:**

- All materials will be the responsibility of participating teams.
- Each team has three class periods to complete its timing device.
- Teams are encouraged to work outside of class.
- All teams must present their projects using the Project Presentation Rubric as a guide.

## **The Rules:**

- Pendulums may not be used as timing devices.
- All timing devices should be one minute timers (plus or minus one second).
- Each member of the team must take part in the construction/testing and presentation of the device.
- Each device must be given a name.
- Each team must create a set of written directions, with illustrations, describing how its timing device can be built.



# Project Assessment Rubric

Adapted from *Inquiry by Design*, Gooding & Metz, 2006 with the permission of the authors.

**All project limitations and rules must be met before using this rubric**

	4	3	2	1
<b>Understanding the Problem</b>	Thorough understanding of problem. Effective use of problem solving strategies.	Problem is generally understood. Evidence of problem solving strategies.	Partial understanding of problem. Attempted use of problem solving strategies.	Unable to demonstrate understanding of problem. Some attempt to respond was made.
<b>Modifications to Original Design</b>	Modifications made to initial design were important improvements and backed by a logical rationale. Documentation present.	Modifications to initial design made no difference in model performance. Rationale for change not present. Documentation present but limited.	Modifications to initial design reduced model performance but were continued.	Documentation and rationale not present.
<b>Operation of Model</b>	The model works smoothly and no adjustments are required.	The model works but is somewhat awkward.	The model works but requires constant adjustments.	The model does not work.
<b>Repeated Operation of Model</b>	Model works repeatedly without lengthy re-set period.	Model works repeatedly but re-setting model is difficult.	Model will work more than once but requires a lengthy re-set period.	Model works only once.
<b>Collection of Data</b>	Data collected, well organized, and appropriately displayed	Data collected, organized, and displayed.	Some data is collected. Ineffectively organized or displayed.	Little, if any data collected. No organization is present.

**BIG BEN**



# Optional Activities



## PART I: SET DESIGN

**Context:** Just as architects create models to help clients visualize the finished product, set and stage designers in the movie and theater industries follow a similar process.

**Scenario:** The Clock Tower containing Big Ben is certainly an icon but it does not stand alone as it is attached to the House of Parliament. A British film company is considering using this location for a major scene in their new 2009 action drama entitled, "The Diamond Cartel".

**Challenge:** Your team assignment is to create a miniature set containing the Clock Tower and House of Parliament. The background for the set will be a drawing of the Clock Tower and the House of Parliament. The remainder of the set, the foreground, could be landscaping and/or other everyday items that would normally be found in this urban environment.

### Limitations:

- All materials will be the responsibility of participating teams except for large sheets of paper that will be provided by your teacher to use for your drawings.
- The drawing of the clock tower must be the same size as the K'NEX model (1:1).
- Teams will have four class periods to design and "stage" their miniature set.
- The foreground may be as wide as the background but may be no deeper than 20 centimeters.

### The Rules:

- The House of Parliament in your drawing must be in approximately the same scale as the Clock Tower model is to the actual structure in London, England.
- All landscaping (trees, bushes and so on) and other common objects (cars, people, etc) must also be in the same scale as the Clock Tower. (These props for your set may be in the form of 2-Dimensional paper or cardboard representations formed with a base that folds under the prop.)
- Teams must document any research conducted in completing this assignment.
- Teams must show how the scale for their set was determined and how the size of the various props were determined.
- The set may be a day time or a night time representation.

## PART II: SET DESIGN

Your set has been accepted but needs the approval of the graphic arts department of the Mega Colossal Humongous Film Company, Inc. This department is not interested in 3-D props. All they want is a picture of the Clock Tower and the House of Parliament drawn in two point perspective.

**Teacher Note:** *The two point perspective provides an opportunity for collaboration with the art department in your school. If that is not possible, then students will have to research this graphics technique and this will add yet another layer of responsibility.*

### Clock Tower Brain Buster

Just when you thought you were done with the Clock Tower one of the writers of "The Diamond Cartel" contacts you with a new problem. "After the Crown Jewels are stolen the thieves do not have time to get out of London so they decide to bury the jewels in plain sight . . . in the ground at the end of the shadow cast by the Clock Tower. Now, this scene is supposed to take place at noon on the first day of summer and we are defining noon as the sun's highest point in the sky. So . . . how far from the Clock Tower would that be?"

If you take on this challenge you must also show all your work including a written description of how you arrived at your answer.

## Lesson 2

# THE FLYING BUTTRESS



### Total Anticipated Time Frame:

Five to six 45-50 minute class periods with additional time required for evaluation options

### Objectives:

Students will be able to:

- Work effectively in collaborative teams
- Identify and investigate strategies and construction techniques to reinforce structures
- Explain and demonstrate an engineering technique used to solve a construction problem
- Construct, modify and evaluate the effectiveness of structures

### Models:

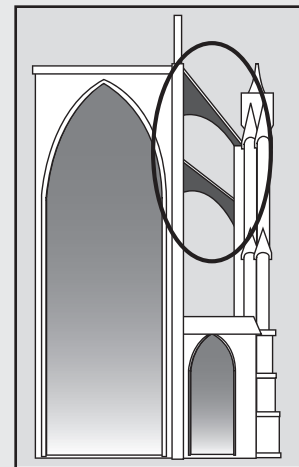
- One group of students can build the Flying Buttress model for this lesson while another group builds the Crane model and completes Lesson 7

### Materials:

- Engineering Marvels: Buildings, Structures and Machines Set
- Metric tape or ruler
- Four table tennis balls attached (taped or glued) to 45 cm of strong thread
- Graph paper
- Copies of **Student Response Sheet #3**
- Copies of the **History of the Flying Buttress** reader
- Copies of **The Design Loop**
- Copies of **The Gothic Design Brief**
- Copies of **The Structural Engineer** reader

**Teacher Notes:** This investigation is designed as a guided inquiry lesson. Students begin with a challenge to construct and test several brick walls for stability. During this phase it is expected that students will collect and record data in a display of their own creation. In addition, students will be required to provide technical/scale drawings of each structure they complete.

Following a class discussion of the results of student investigations the teacher will introduce the concept of the Flying Buttress (a projection transparency of a famous flying buttress would be very helpful), require that students read the historical description of this architectural innovation. Armed with this information and the experiences they gained during experimentation, students will then apply what they have learned as they pursue a specific design challenge. It is suggested that students be familiar with **The Design Loop** (see Teacher Notes for a copy) as a viable process for solving design and technology problems when they begin the design challenge. The evaluation phase of the lesson provides a series of five options that can be completed in part or in whole to provide a wide range of learning opportunities for students.



# THE FLYING BUTTRESS

## Lesson 2

### TECHNICAL/SCALE DRAWINGS:

For the purposes of these investigations, scale/technical drawings are defined as accurate two-dimensional representations of objects. These illustrations should include: color, dimensions, labels when appropriate, and multiple views (top, front, and side) if necessary for clarity. Additional features include a title, name of architect, drawing key that includes color code and scale. Certainly you can vary the details from the list above to address time constraints and the specific goals of your curriculum.

### ENGAGE:

Begin by asking students, “Do you think there is any relationship between the thickness of a wall and its maximum height and stability? Can we build a sturdy, stable wall that is one brick thick and 40 meters high? Why or why not?” Ask students to discuss this question in small groups followed by a class discussion, including justification for their contentions.

Time Frame approximately 20 minutes



### EXPLORE:

Distribute and review copies of **Student Response Sheet #3** with students. The students will be testing the stability of tall, thin walls made from K’NEX Bricks. They will test the stability of the wall as the force of a table tennis ball strikes the top of the wall. Be sure that the students understand that they are each responsible for creating a display (table, graph, etc.) for their results and/or a **technical/scale drawing** to communicate the results of the activities outlined on the Student Response sheet. Require students to use their data to “Make a Rule” about the thickness of a wall, its height and its stability. **Student Response Sheet # 3** will guide students as they explore. Four groups of students will need 110 full bricks and 12 half bricks each for this investigation.

Time Frame approximately 45 minutes



### EXPLAIN:

Ask the students to describe what they discovered about the thickness of brick walls, their height and stability. Have the students share the “rules” they created to summarize their findings. Tell the students that one unique way to solve this problem was discovered during medieval times. Ask students to read the **History of the Flying Buttress** to learn more about this architectural innovation that dates back over 700 years. Discuss the reading with the students before you continue. Projected pictures of flying buttresses from the Internet will provide additional information and clarification to students.

Time frame approximately two 45 minute periods.



**ELABORATE:**

Ask students to read, discuss and begin **The Gothic Design Brief Challenge**. If this is your students' first experience with a design challenge, it is suggested that you familiarize them with the **Design Loop** diagram and its function prior to this investigation.

Time Frame approximately 45 minutes

**EVALUATE:**

When the students have completed The Gothic Design Brief Challenge consider broadening the experience by asking them to complete the extension activities provided.

**Option 1:** Instruct students to construct flying buttress models following the diagrams in the building instruction booklet. Separate the two opposite walls on the model so two groups of students will be able to have an identical section of a wall that is six blocks long and has three flying buttresses. Provide students with table tennis balls and thread for testing. Ask students to respond to these questions: 1. Can you identify a flying buttress on this model? Describe the flying buttress. 2. If you test this wall with your table tennis ball system, do you think the wall will be stable? Test the wall and describe what you discover. 3. What features of the brick wall with flying buttresses make it a stable structure? The answers provided to these questions will help students to apply what they have read and learned about flying buttresses to a model of such a support system.

**Option 2:** Instruct students to build the Flying Buttress model as pictured in the building instruction booklet. Notice the “tie” or connecting brace that is used to connect the two walls.

- What purpose do you think this tie serves? Design a way to test your inference, conduct the test, and write a brief description of what you discovered.

**Option 3:** Ask students to research the other types of buttresses and create models of these buttresses using K'NEX Bricks.

**Option 4:** Assign students to look for examples of buttresses around your school and community. Take digital photos of those buttresses and prepare a PowerPoint™ presentation for your class. Include digital images of models you create of these buttresses from K'NEX Bricks.

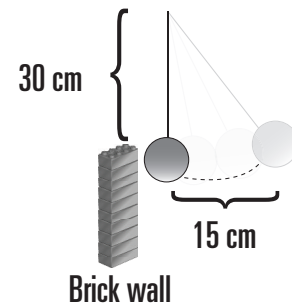
**Option 5:** Provide students with copies of **The Structural Engineer** reader. When they have completed the reading ask them to describe how and why the role of the structural engineer has changed since the 13th century. The students' answers to this activity will be better informed if they are provided with additional time to discuss the question with classmates and to research further.

Times will vary based on the number and type of extension activities chosen.



“Is there a relationship between the thickness of a wall, its height and its stability?”  
What do you think? List your response and a brief statement that indicates why you think that is the case.

Your teacher will provide you with bricks for testing. Design an activity that will enable you to determine the stability of a tall brick wall when a force acts on one side of the top of the wall. The diagram below may provide you with some ideas. Describe what you plan to do below. Your brick wall can be one or two bricks long and as tall as necessary for your testing.

**RESULTS:**

Create a technical/scale drawing and/or data display to communicate the results of your efforts on the back of this page.

**RULE:**

Write a rule to explain the relationship between the height of a wall and its stability.

**EXPLAIN:**

Does a thin brick wall remain more stable when it is tall or when it is short? Explain your answer.



# Student Response Sheet

# 3

Name: \_\_\_\_\_

Date: \_\_\_\_\_

Do you think thicker walls would be able to withstand larger forces? How could you test this?

What advantage would it be to have thinner, taller walls in buildings?

Can you propose a way to construct tall, thin-walled buildings that are able to withstand forces pushing the tops of the walls outward?

**THE FLYING BUTTRESS**

# The Gothic Design Brief Challenge



## The Context:

Historically, architectural innovations often come about because of a specific need, the discovery of a new material or process, a creative application of existing techniques or a combination of several factors.

## The Scenario:

The King of your shire wants to rebuild the small, worn-out, thick-walled Royal Church with a larger, taller, thin-walled structure with huge windows. The Royal Builders have decided to reuse all the stone blocks from the old structure to reduce the cost of the new church but only know one method of construction...that same way the old church was built, and this method cannot support tall walls with large windows.

## The Challenge:

Good King Robert sent forth a declaration (which is generally what kings did at that time) seeking help for his Royal Builders. The declaration went something like this...

**“Hear ye all within the Kingdom of this shire.**

**It has come to my attention that my royal builders are unable to build a tall, thin-walled church with large windows that will allow the light of the sun to shine in. Therefore, by royal decree, I lay down this challenge and offer a hefty reward to anyone creative enough to solve this royal dilemma. It requires that a sample wall be built as a model for my royal builders to follow and test.”**

## The Limitations:

- Team members must collaborate on the design and construction of the sample wall.
- At least 25% of the surface of each wall model submitted must be clear for windows.
- Each team must submit a technical drawing of the proposed structure before gathering construction materials.
- Design teams may only use the K’NEX materials not being used by students completing Lesson 7.
- All teams have one class period to complete their task.

## The Rules:

- The walls must be two bricks in length and only *one brick wide*. Walls must be at least 20 bricks tall.
- All walls must be tested for stability and the data clearly displayed in some manner.
- Teams *may not test* their own walls...only the walls of other teams
- Once experimental data is collected all students must write an illustrated report to the royal builders explaining how to construct tall, thin-walled structures.

## Lesson 3

# THE ARC DE TRIOMPHE



**Anticipated Time Frame:**  
Eight to nine, 45-50  
minute periods at the  
discretion of the teacher

### Objectives:

Students will be able to:

- Construct a model of the Arc de Triomphe
- Create a technical/scale drawing of Arc de Triomphe model
- Explore the career opportunities of the city/site planner
- Propose a design for the area surrounding the Arc de Triomphe

### Models:

- One group of students can build the Arc de Triomphe model for this lesson while another group builds the Windmill model and completes Lesson 6

### Materials:

- Engineering Marvels: Buildings, Structures and Machines Set
- Copies of **The Arc de Triomphe** reader
- Copies of **The City/Site Planner** reader
- Copies of the design challenge **Paris in the Springtime**
- Graph paper (various grid dimensions if available)
- Sheets of poster or butcher paper for student site plans
- Metric tapes or rulers
- Transparent tape
- Colored pencils, crayons, markers
- Scale drawing cards for the scale lottery (2 cm to 1 cm, 1 cm to 1 cm, 1 cm to 2 cm, 3 cm to 1 cm, etc.)
- Copies of **Student Response Sheet #4**

### Teacher Notes:

*During this lesson, students will make scale/technical drawings of a K'NEX model based on a ratio they randomly select in a drawing. It is suggested that multiple copies of the ratios be prepared on 3" X 5" cards so there are scale cards for teams of two. Students will be expected to work in pairs or a group of three as they complete their measurements of the model and their scale drawings (Two or more groups of students may share measurements to allow more students to participate in this activity). When graph paper is provided during the activity remind students that the graph paper is provided to assist them as they make their drawings as square as possible. It is much easier to draw a perpendicular or horizontal line on their paper when the graph paper guide lines are present for reference.*

**A Reminder:** *For the purposes of these K'NEX investigations, scale/technical drawings are defined as accurate two-dimensional representations of objects. These illustrations should include: color, dimensions, labels when appropriate and multiple views (top, front, and side). Additional features include a title, name of architect, and drawing key that includes color code and scale. Certainly you can vary the details from the list above to address time constraints and the specific goals of your curriculum.*



# THE ARC DE TRIOMPHE

## Lesson 3

### ENGAGE AND EXPLORE:

Ask students to create an efficient way to construct the Arc de Triomphe model, from the renderings in the building instruction booklet, making sure that each member of the team is actively involved. After the students have crafted a plan of attack allow them to begin construction on their model. Have students read **The Arc de Triomphe** reader. Ask each student to list two questions they would like to explore about the Arc de Triomphe now that they have seen the model and have had a chance to learn about its history. (As a homework assignment you may ask students to do research to find the answer to at least one of their questions).

Time Frame approximately 45 minutes



### EXPLAIN:

Once the model has been completed, ask the students to write a brief description of the construction process they followed and how they provided opportunities for each person to be actively involved. Also, ask the students to describe any problems they had and what they would change if they were presented with a similar situation in the future. When the students have completed their writing ask them to share their reflections.

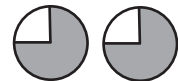
Time Frame approximately 40 minutes



### EXPLORE:

Tell the students that you will now conduct a drawing to select a number representing the scale they will use to create a technical/scale drawing of the model they have constructed. (If students are not familiar with how to read the scale on their card, review the process with them. For example, a scale of 1 cm to 2 cm means one centimeter on the paper is equal to 2 cm on the model.) Have students gather the supplies they believe are needed to complete their task. It should be noted that some of the students will be able to complete their scale/technical drawings on a single sheet of graph paper while other students will need to tape several sheets together. It may be prudent to suggest that students make their drawings *LIGHTLY* in pencil until they are satisfied with the result.

Time frame approximately two 45 minute periods.



### ELABORATE:

The Arc de Triomphe is one of the largest of its kind in the world and continues to be a center of national pride for the French people. The area surrounding the Arc has changed dramatically over the years. During this phase of the lesson students will redesign the area around the Arc to better coincide with the grandeur of the structure. This lesson segment is directed by a design brief challenge entitled "Paris in the Springtime." (Distribute copies for the students to review.) Provide students with copies of **The City/Site Planner** reader and ask them to read about this career opportunity. Assign students to write a one paragraph response to this question: How does the role of the city/site planner relate to the task you are about to undertake?

Time frame approximately two 45 minute periods.



**EVALUATE:**

The result of the “Paris in the Springtime” design brief was a two dimensional, *top view only* representation that provides multiple opportunities for evaluation. The second-tier evaluation component of this lesson requires students to convert their two-dimensional scale drawings to three-dimensional models (if time constraints limit the time students can spend on the project, the 3-dimensional model may be deleted or assigned as a project to be completed outside of class). The **Student Response Sheet #4** has been provided to help guide students through this process. In addition, it is suggested that the scale drawings be taped or glued to heavy cardboard as a support structure for the additional materials that will be placed on the redesigned city plan.

Time Frame approximately 45 minutes



# Paris in the Springtime Design Brief



## **The Context:**

The culture of a society is often communicated through the preservation of its past.

## **The Scenario:**

Napoleon commissioned the largest arched monument in the world in 1806 as a tribute to the French Army, the Arc de Triomphe. The French Government is interested in renovating the area around this monument from a crowded, urban setting jammed with traffic to a tranquil, respectful memorial poised at the center of twelve radiating avenues.

## **The Challenge:**

Your city planning team has been contacted to de-urbanize and redesign the area surrounding the Arc de Triomphe to make it more pedestrian friendly and attractive to tourists. French officials have stipulated that the restoration include walking paths, floral and water gardens, a variety of trees, rest and picnic areas, access to mass transit and unobtrusive parking for automobiles. Your team must create a two-dimensional (**TOP VIEW ONLY**) plot plan for the area surrounding the Arc.

## **The Limitations:**

- The original twelve avenues that radiate out from the Arc must remain in the plan.
- Each team will have three class periods to complete its design.
- The design should allow for the smooth flow of visitors from one place to another.

## **The Rules:**

- All park designs must:
  - \* be drawn to scale so the Arc de Triomphe could actually be placed on their drawing for presentation purposes;
  - \* use color to highlight and identify design features;
  - \* use appropriate symbols for clarity;
  - \* include a legend;
  - \* be drawn using an aerial or top view only.
- Each team member must create a written description of its design, including a rationale for the features that have been included.

## **Resources:**

- Several map programs on the Internet include close-up, aerial views of the streets, avenues, and roads surrounding the Arc de Triomphe. These images may be very helpful as you complete these designs. Some of these programs also allow you to view a satellite image of the area surrounding the Arc de Triomphe.



# Student Response Sheet

# 4

Name: \_\_\_\_\_

Date: \_\_\_\_\_

**Directions:** Your team has completed the “Paris in the Springtime” design brief in which you developed a two-dimensional view of an urban renewal project around the Arc de Triomphe in the city of Paris.

Your next step is to convert this two dimensional plan into a three dimensional model. Your team will need to creatively use a variety of materials to replace the symbols that are represented on your plan. For example, you might have used a symbol like this ☁ to represent an aerial view of a tree on your plan. Now, because you are converting this plan to a model, you will need to actually “build” small trees to replace those tree symbols. (Consider full-color, 2-dimensional representations that have folded tabs at the base to act as stands.)

Keep in mind that any three-dimensional object also needs to be in the same scale as your plan. For example, the Arc de Triomphe is nearly 50 meters tall and your K’NEX model is 22 centimeters tall. Based on that relationship, a tree that is 15 meters tall would be about 6.6 centimeters tall in your 3-D representation.

**Make a List:**

Have a team discussion about what objects will need to be created, what size these objects will need be to fit the scale of the model and what materials might be used to create these objects. Record your thoughts in the table provided.

Object Name	Symbol	Actual Size	Scaled Down Size	Possible Materials

**THE ARC DE TRIOMPHE**



# Student Response Sheet

# 4

Name: \_\_\_\_\_

Date: \_\_\_\_\_



## Show and Tell:

Once your three dimensional model is completed, your team will then have to craft a brief, *three minute* sales pitch to the French Government about your city plan. Remember, this presentation is intended to persuade the government to select your plan for their urban renewal project. Your presentation may not be more than three minutes long. Refer to the Team Presentation Rubric as a guide for your presentation.

THE ARC DE TRIOMPHE



# Team Presentation Rubric

Adapted from *Inquiry by Design*, Gooding & Metz, 2006 with the permission of the authors.

	4	3	2	1
<b>Group Participation</b>	Each member contributed to the presentation, knew what to do, and when to do it. Each member showed confidence.	Each member contributed to the presentation.	Majority of the members contributed to the presentation.	Only a few members contributed to the presentation.
<b>Organization</b>	Organized, sequential, concrete, on topic	Organized, sequential, and on topic	Somewhat disorganized and off topic at times	Disorganized, jumped from one idea to another
<b>Transitions</b>	Transitions from one presenter to the next were successful and clear.	Transitions from one presenter to the next were evident.	Transitions not always apparent.	No transitions
<b>Closing</b>	Concise, effective, and summarizes the main idea	Clear, effectively brought to an end	Somewhat abrupt, short	No closing
<b>Volume</b>	Everyone could be heard and was confident.	Everyone could be heard.	Majority of the group could be heard.	Only a few could be heard.
<b>Assessment</b>	Focused on most important points; accommodations made for different learning styles of all classmates	Focused on most important points; some accommodations made for different learning styles of classmates	Focused on some important points; no accommodations made for different learning styles of classmates	Not focused; no accommodations made for different learning styles of classmates

# THE FIRST IRON BRIDGE

## Lesson 4

### Objectives:

Students will be able to:

- Work effectively in collaborative teams
- Design a plan to complete an assignment that differentiates responsibilities
- Prepare a scale drawing of a model
- Design a bridge structure to meet a challenge

### Materials:

- Engineering Marvels: Buildings, Structures and Machines Set
- Long sheets of butcher paper or similar paper from a roll (a 6' long piece for each group)
- Crayons, markers, meter sticks
- Copies of **History of the First Iron Bridge** reader

### Total Anticipated Time Frame:

Four 45-50 minute class periods

### Models:

- Two groups of students can work simultaneously to build a large model of the first iron bridge. Each instruction booklet includes instructions for 1/2 of the model

## Activity # 1:

### ENGAGE:

Prior to this activity, provide students with copies of the **History of the First Iron Bridge** reader and instruct them to read the selection. Inform students that they are going to build a model of this bridge working in two construction teams. Just as Darby fashioned his pieces for the bridge from iron and assembled them on site, the students will use pieces fashioned from plastic to create a model of that structure. Ask the class to describe what an assembly line is. Let them discuss and share their understandings of this concept with one another. Provide and discuss examples of popular assembly line productions. A well known form of the assembly line is the moving assembly line, which was developed and made famous by Henry Ford and the *Ford Motor Company* early in the twentieth century.

Time Frame approximately 15 minutes

### EXPLORE:

Establish two construction teams for this activity. Show the class the instructions for the K'NEX model of the first Iron Bridge. Students will notice that one half of the instructions are found in each of the building instruction booklets. Explain to the class that you would like each team to create a plan to construct their half of the Iron Bridge model that has every person on their construction team directly involved. The challenge will be to see which team finishes their half of the bridge the fastest. Once the teams have decided on a plan have them build the bridge. Be sure to note the amount of time required to complete the bridge.

Time Frame approximately 45 minutes

### Teacher's Notes

*Teacher Note: The Engineering Marvels: Buildings, Structures and Machines Set has materials to build one first Iron Bridge model.*

**EXPLAIN:**

Following the bridge construction have the individual students complete a reflective writing activity that has the winning team describe what aspect(s) of their plan made them the winning team. The losing team should describe what aspects of their construction plan caused them to lose the challenge, in their opinion. Students should support their statements with examples and explanations.

Time Frame approximately 30 minutes 

**EVALUATE:**

Facilitate a discussion that enables students the opportunity to share their thoughts relative to the successful completion of the challenge, and to arrive at some consensus as to a strategy that would be most likely to be successful in the future.

Time Frame approximately 20 minutes 

**Extension Activity # 1:** When building models during the remainder of this unit of study, employ strategies discussed and agreed upon during the consensus phase of the evaluation activity above.

**Extension Activity # 2:** Instruct students to make a two-dimensional scale drawing of the first Iron Bridge model using a long sheet of paper from a roll and centimeters as their unit of measure. In this instance, the scale of the drawing will be 2 : 1 or, in other words, two centimeters on the drawing will be equal to 1 cm on the model. As this activity is based on measurements made of the actual model, an entire class of students can collect the data and work in small groups to complete the activity. The end products can be enhanced with scenery and background material that is consistent with the scale of the drawing. These scale drawings can then be displayed in the classroom, hallway, or in the library.

Time frame approximately two 45 minute periods.  

**Extension Activity # 3:** The first Iron Bridge was an arch bridge built to allow boat and barge traffic to easily move along the waterway below the traffic. Ask students to research the arch bridge style and to report on the characteristics of the arch bridge that made it an excellent bridge for the English countryside. Instruct students to note that each end of the bridge has massive piers of concrete and stone. Students should address the purpose of these piers and their relationship to the arches that make up the rest of the bridge.

Time frame approximately 45 minutes. 

**Extension Activity # 4:** The arch bridge was not the only option for a bridge in Shropshire. Instruct students to design and construct another style of bridge that has a span to match that of the model arch bridge used earlier in this lesson. Students should be able to list the style of bridge they have designed and indicate the characteristics of the bridge that make it suitable for use in Shropshire.

Time frame approximately 45 minutes. 



# TOWERS OF TRIANGLES

## Lesson 5

### Objectives:

Students will be able to:

- Construct and evaluate the effectiveness of a variety of structures
- Experiment with the use of triangles to strengthen structures
- Modify structures for an intended purpose
- Demonstrate an understanding of scale

### Materials:

- Engineering Marvels: Buildings, Structures and Machines Set
- Copies of **The Triangle Puzzle**
- Copies of the picture of the Eiffel Tower (two per group)
- One completed Eiffel Tower Model
- Graph paper (8 1/2" X 11")
- Copies of **Student Response Sheet # 5**
- Copies of **The History of Towers** reader

### Total Anticipated Time Frame:

Eight 45 minute class periods at the discretion of the teacher

### Models:

- Two models of each of the following towers can be built simultaneously. Two different models from this list can also be built simultaneously
- CN Tower
- Seattle Space Needle
- Eiffel Tower

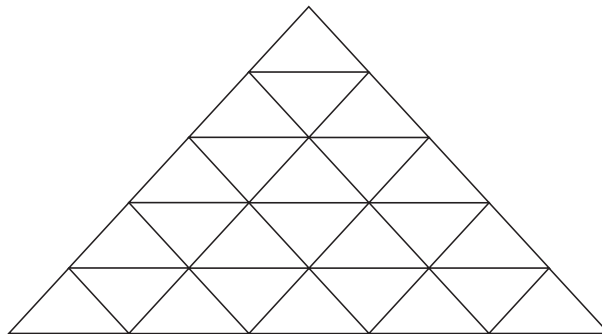
### Teacher's Note:

*A majority of the structures in this unit use some form of the triangle to maintain the integrity of the structure. These triangles may be obvious in such structures as the Eiffel Tower or subtle and unassuming as in the graceful arches of the Iron Bridge. Nonetheless, the triangles are there. This simple, yet incredibly strong and effective building shape has appeared throughout history in almost every culture regardless of the type of construction materials used, the climate of the area, or the technology of the time period.*

### ENGAGE 1:

Make copies of **The Triangle Puzzle** for each student as well as an over head transparency. Project the problem for students and tell them they have 15 minutes to solve the problem.

How many triangles do you see in this picture?



Distribute copies of the puzzle to students and allow them to begin work on the puzzle. After 15 minutes, have students form groups of three and share their solution strategies.

Time Frame approximately 25 minutes

Ask several students to use an overhead transparency of The Triangle Puzzles and an erasable marker to demonstrate their solution to the triangle problem. In addition, consider giving students the same problem with multiple copies of the puzzle, in smaller scale, on the same piece of paper. This multiple format will allow them the opportunity to color code their triangles for increased accuracy as they count and to attempt a variety of solution strategies. Since some triangles are singles, some are constructed of multiples and some are upside down, be prepared for students to reflect and discuss this problem for some time.

Ask the students, "Is there a pattern between the number of rows and the total number of triangles? If a 7th row of triangles was added to the bottom what would the total number of triangles be? What about an 8th row?"

**Time Frame approximately 25 minutes**



### EXPLORE 1:

Ask the students to carefully observe the picture of the Eiffel Tower and respond to the following questions:

1. How is the Eiffel Tower like the triangle puzzle?
2. Why do you think so many triangles were used in the construction of the tower?

Students have a model of the Eiffel Tower made from K'NEX. Ask them to describe how the architecture of the model is different than that of the real tower. (Students should identify the fact that the model does not include triangles in its structure.)

Ask the students to divide the remaining bricks, rods, and connectors in the Engineering Marvels set between their two groups and then to build a tower of their own design that is as tall as the existing Eiffel Tower model and incorporates triangles in the structure for added support and strength. Students should devise a way to test the strength of their two towers and record the results of their testing. Side-by-side diagrams of the existing tower and their new tower should be prepared so students can present their work and explain the impact of using triangles in the construction of their tower.

**Time frame approximately two 45 minute periods.**



### EXPLAIN:

Students will use their own diagrams, discoveries, and models to present and demonstrate the modifications they built into their tower and compare their tower to the Eiffel Tower model.

**Time frame approximately 45 minutes.**



### ELABORATE:

The Eiffel Tower is 321 meters high, including the antenna. Have the students measure the K'NEX model and determine the scale of the model as compared to the actual structure. How high would the model have to be for the scale to be 1/300th (which is sometimes written 1:300 and is read one unit on the model equals 300 units on the actual structure)? Challenge students to modify their models of the Eiffel Tower to match the 1:300 scale, and to then prepare a scale drawing of the new model that will fit on a single sheet of graph paper.

**Time frame approximately 45 minutes.**



# TOWERS OF TRIANGLES

Lesson 5



TOWERS OF TRIANGLES

**ENGAGE:**

Have student teams build the Space Needle and the CN Tower. Once these towers are completed ask the students to make comparisons between the three structures. Compile a list of similarities and differences on the chalkboard or on chart paper. The three models cannot be built simultaneously so students will have to disassemble one of the towers to make the third for the sake of these comparisons. Based on the known height of the actual structures and the measured model height, determine the scale of each of the models.

Time frame approximately 45 minutes.



# TOWERS OF TRIANGLES

## Lesson 5

### EXPLORE:

This particular exploration is a diversion from the general hands-on format generally associated with this component, and is more of a minds-on component. Provide students with a copy of The History of Towers reader that includes descriptions of the Eiffel Tower, the Seattle Space Needle and the CN Tower. It is suggested a modified Jigsaw strategy be used to disseminate the information about these three towers in conjunction with **Student Response Sheet #5**. For example, team members first decide, or are assigned, to research one of the three towers. The students should then deploy in focus groups to review and to take notes about their respective towers.

Time frame approximately 45 minutes.



### EXPLAIN:

Once the focus groups have gathered the required data, the original team members will reconvene and share the data about their respective towers with the others in their team. At this point, each original team will now have information about all three towers. Additional research may be needed to gather all the required information. Students may gather this information outside of the classroom if resources are available for them to complete this work. Data from each team member will then be combined to create a team summary about all three towers during the following class session.

Time frame approximately 45 minutes.



**ELABORATE:**

The Seattle Space Needle has a rotating restaurant at the top of the tower. Instruct students to redesign the K'NEX model so that the platform (or a redesigned platform) will rotate if you push it with your hand. Students should also briefly describe how they think the actual restaurant at the top of the Space Needle addresses its water, electrical, and other service needs if the restaurant is in motion.

Present your model and describe what your team did in order to successfully complete this task. Also, ask students to present their solutions to the question of how the restaurant is able to receive services if it is in motion. (In actuality, the kitchen portion of the restaurant is stationary in the center of the tower. All services are delivered to the kitchen. It is only the waiters, waitresses, and customers exiting the elevator that step onto the moving portion of the restaurant, which includes all of the tables and chairs.)

Time frame approximately 45 minutes.

**EVALUATE:**

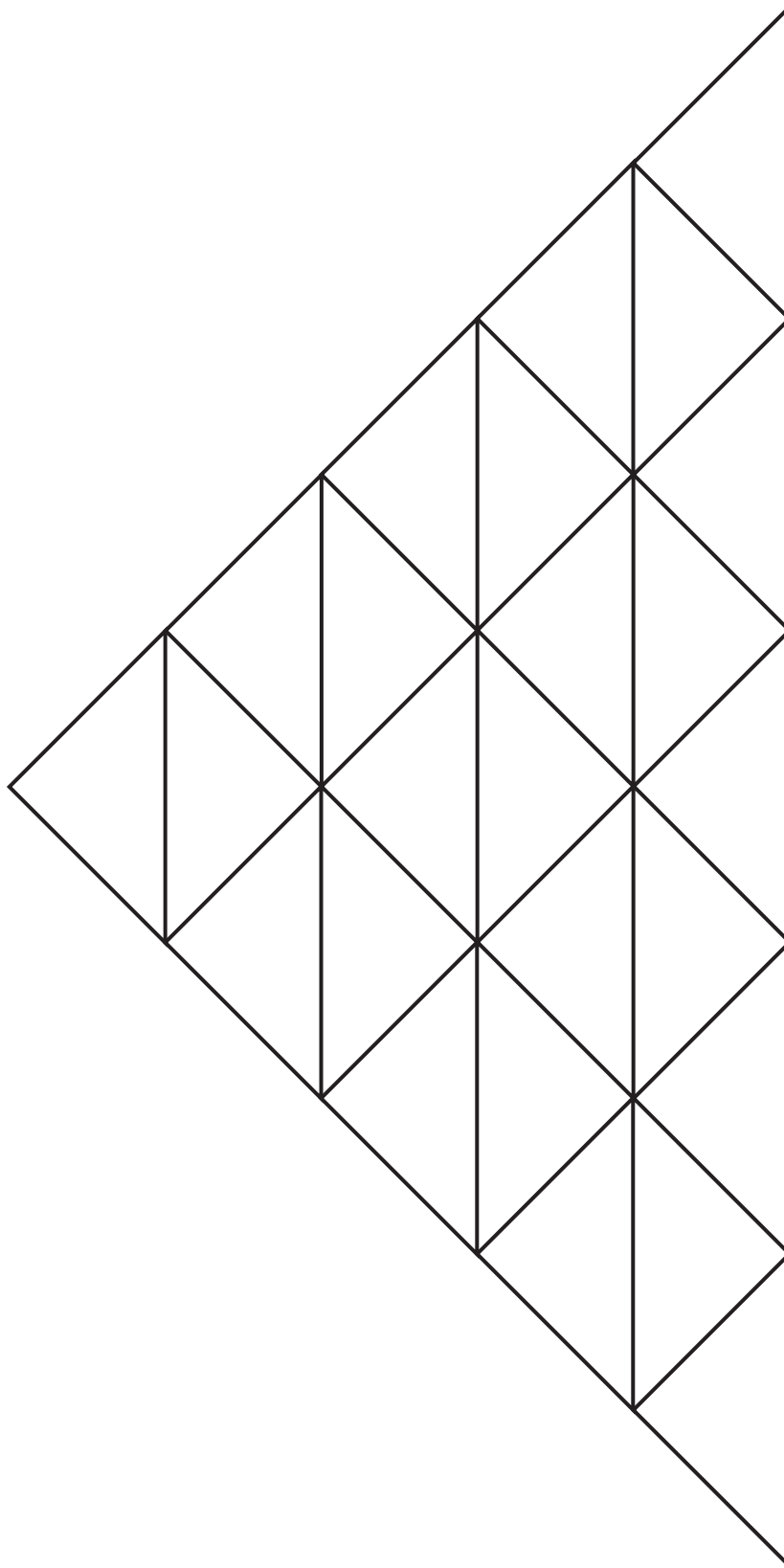
This evaluation segment can be considered a performance assessment. In this investigation, entitled "Tower Power", the students are challenged to create a 150 cm tower using nothing more than newspaper and masking tape. As an additional quest, students will also design a way to balance a golf ball at the top of the tower cantilevered 12 cm away from the center of the structure.

Time frame approximately 45 minutes.





### THE TRIANGLE PUZZLE



How many triangles do you see in this picture?

### TOWERS OF TRIANGLES



# Student Response Sheet

# 5

Name: \_\_\_\_\_

Date: \_\_\_\_\_

**Directions:** Your research team has been given the task of designing a page for a book about famous towers. Descriptions of the Eiffel Tower, the Seattle Space Needle, and the CN Tower have been supplied as a source of information. More research will be needed as you search for all of the required information.

Your description for each tower will fit on a single page, contain at least one picture of the tower (with a caption), and list the references used. The tower story should focus on the following areas, but not necessarily in the order they are presented. Be as complete as possible; if information on one of the categories is not readily available indicate that in the text of your page. Your research team may choose to provide some of the information below in the form of lists after you have determined which information would be best presented in that format.

- Cost
- Cost overruns
- Materials used
- Length of construction (starting date – completion date)
- Safety issues addressed or faced during construction
- Purpose of structure
- Special features of the tower
- Problems before, during and after construction
- Technology used to construct each tower
- Unique engineering strategies employed
- Environmental concerns (weather, soil conditions, etc.)
- Name of architect/designer
- Location of the structure





Adapted from *Inquiry by Design*, Gooding & Metz, 2006 with the permission of the authors.

## The Context:

Thomas Edison successfully used bamboo poles as reinforcing rods in the construction of a concrete swimming pool. Plastic soda bottles are melted and spun into micro fiber fill for insulating winter clothing. Could newspaper be used in a unique way?

## The Scenario:

Each year the city holds its annual “Creative Engineering Competition (CEC)”. The director of your engineering firm has selected you and your team to be this year’s company representative at the CEC.

## The Challenge:

The challenge is to construct a model tower with a cantilevered, spherical shaped restaurant at its pinnacle. The rules committee has determined that the only materials that can be used are newspaper and masking tape. A golf ball will serve as the restaurant.

## The Limitations:

- The tower may only be constructed of newspaper and masking tape.
- The tower may not be taped to anything for support.
- The tower must be at least 150 cm tall.
- The golf ball must be at the top of the tower and lean out from the main tower a minimum of 12 cm (as measured from the center of the tower to the center of the golf ball).
- Each team has 45 minutes to complete the tower.

## The Rules:

- Each team member must be actively involved.
- There are costs associated with this challenge and your team must keep an accurate account of how much money it spends.
  - Newspaper = \$2.00 per full, double sided sheet (only full sheets may be purchased)
  - Masking Tape = \$.25 per centimeter
- When finished, each team must divide the total cost of its tower by its height in centimeters. The lowest cost per centimeter tower will be declared the winner, providing that the other construction parameters have been met.
- No materials may be returned.
- Any team that finishes early will receive \$1.00 off its construction costs for each full minute.
- Extra time may be purchased by any team at \$2.00 per minute up to a total of five minutes.



## Tower Power

# TOWER POWER

- Each team member must write a report to the CEC detailing the following. (This may be done after the 45 minute building time.):
  - **The planning and construction of their tower**
  - **The cost of the tower**
  - **The final height**
  - **The basic shape or shapes that were used**
  - **How the newspaper tower compares to the K'NEX towers**
  - **How the generally flimsy newspaper was changed to be structurally stronger**
  - **Problems that occurred in the construction**
  - **How those problems were resolved.**

# THE WONDEROUS WINDMILL

## Lesson 6

### Objectives:

The students will be able to:

- Modify the design of a windmill for investigative purposes
- Evaluate the effectiveness of design modifications
- Collect, organize, graph and interpret investigative data
- Design and conduct a “fair test” investigation with appropriate data displays

### Models:

- One group of students can build the Windmill model for this lesson while another group builds the Arc de Triomphe model and completes Lesson 3

### Materials:

- Engineering Marvels: Buildings, Structures and Machines Set
- A window or box fan
- Copies of **Student Response Sheet # 6**
- Copies of **Student Response Sheet # 7**
- Copies of the **History of Windmills** reader
- Common classroom materials, glue, transparent tape, a variety of different types of paper
- Pieces of fabric (8” X 12” or larger)
- Aluminum foil and/or plastic wrap
- A ball of string



### Total Anticipated Time Frame:

Six to eight 45-50 minute lessons at the discretion of the teacher

### ENGAGE:

Tell the class that you have plans for a structure that you want them to construct, but that special rules need to be followed during the construction process. Pass out copies of the Construction Conundrum design brief for the students to review. It is suggested that a discussion be conducted after the students have read the investigation, with special emphasis being placed on the Limitations and Rules sections. Use probing questions to ensure that the students completely understand their responsibilities and your expectations. In addition, consider providing time for the student teams to discuss a plan of attack.

Time Frame approximately 45 minutes

### EXPLORE:

Once the students have settled on a plan, allow them access to the materials. Keep in mind that the Foreman from each group is the only person with permission to view the diagrams of the windmill. The Foremen may refer to the diagrams as many times as is necessary. Remind them that they may not run and must keep their hands **behind them at all times while talking with their team**. This activity stresses the importance of verbal communication and vocabulary. The team Foreman will be tempted to use their hands to point out pieces and to show how pieces need to be oriented. Keeping their hands behind their backs will help to remind them that they are only to use their verbal skills to direct their team.

Time Frame approximately 45 minutes

**EXPLAIN:**

The written assignment, which is found in the rules section of the design brief challenge, is significant because it sets the stage for clarifying and increasing the importance of the communication process which is so essential in all team assignments. Ask the students to share their responses to questions about the challenge they have just completed. How did they feel as contractors or as foremen? Why is accurate communication so important? How might the process be improved? Reflection is an important aspect of learning that requires time to think, share, and discuss.

Time Frame approximately 45 minutes

**ELABORATE:**

In this phase the students will be asked to investigate the windmill structure they completed earlier. This device contains a number of moving parts and lends itself to redesign and modification. **Student Response Sheet #6** guides students as they investigate the windmill and find possible answers to a number of questions. It is anticipated that these queries may take more than one class period, based on the number of questions investigated and the extent of the solutions generated. Be sure that students decide upon and record what windmill “performance” means to them before they begin any investigations so that they will have a reference point for comparison. In other words, they are going to decide how they are going to measure performance of the windmill. Will they mark one blade with masking tape and use revolutions per minute (rpm) to measure windmill performance? Will they count the number of times the vertical arm of the pump mechanism rises in one minute for their measurements? Or, will they come up with a completely unique way to measure the performance of the windmill? There are six **Questions to Investigate** listed on **Student Response Sheet #6**. Students should not disassemble their windmills at the conclusion of this activity. They will use the windmills during the evaluation phase of the lesson.

Time frame approximately three 45 minute periods.

**EVALUATE:**

Activity # 1 - During this part of the lesson it is expected the students will go beyond the initial questions regarding the windmill blades to investigate the mechanics of the device. Common classroom materials and string may be needed to complete this section. **Student Worksheet #7** will direct the students as they complete this hands-on evaluation activity.

Activity # 2 – Windmills have been used as a source of energy for more than two thousand years. Distribute copies of the **History of Windmills** reader and provide time for the students to read the material. Using this information as a starting point, have students describe in writing how advances in science and technology have made it possible for the role of the windmill to change over the course of history. Ask students to describe the role they see for windmills in the future. (You may wish to allow students a set amount of research time [i.e., one class period] to gather information for this activity.)

Time frame approximately two 45 minute periods.



### EXTENSION ACTIVITIES:

Research provides an opportunity for students to explore windmills in greater detail. With all of the interest in alternative energy sources, the windmill has received a great deal of national and international attention. Print and electronic media now contain a great deal of information related to windmills and their part in helping the world address energy and environmental concerns. Suggest that your students brainstorm some questions related to windmills that they would like to explore and then provide them with the opportunity to investigate.



# Student Response Sheet

# 6

Name: \_\_\_\_\_

Date: \_\_\_\_\_

## THE WONDEROUS WINDMILL

Your first challenge is to modify the windmill that you constructed earlier to make it perform better than it does currently.

- How can you measure how the windmill performs now? Describe how you will measure the performance of the windmill and then complete an activity to actually measure some aspect of its performance. Your teacher will provide a fan that you can use to provide a source of wind.
- Make modifications to your windmill and/or its blades so that it will perform better than it does now.
- Your teacher will provide a variety of materials you can use to improve your windmill.
- Keep notes of the changes you make and describe how the windmill performs better than before. Provide evidence that the windmill performs better.

Design and conduct a “fair test” experiment to find an answer to the **Questions to Investigate** listed below that your teacher has selected for your group. Record each question you are assigned from the list on a separate sheet of paper or a separate page in your science notebook. Be sure to include:

- The question you intend to answer
- An accurate description of the steps you intend to take to answer the selected question
- The materials you intend to use
- What you will measure
- How you will display this data
- How the results relate to the problem question

### **Questions to Investigate:**

- Does the number of windmill blades make a difference in the performance of the windmill?
- Does the size of the windmill blade make a difference?
- Are flat blades as effective as twisted blades?
- Do covered blades turn faster than uncovered blades?
- Are solid covered blades as effective as blades with some open spaces?
- Are windmills as effective if the blades are mounted horizontally?

# Costruction Conundrum



Adapted from *Inquiry by Design*, Gooding & Metz, 2006 with the permission of the authors.

## The Context:

Direct communication is more effective than indirect communication.

## The Scenario:

The small architectural firm of Mega Clean Air, Inc. has designed a new windmill as an alternative energy source and they are interested in creating a wind farm. They have built a model of the structure, and plan to hold an open bid for all construction companies. Your organization would like to participate but obviously needs to see the model prior to submitting your bid.

## The Challenge:

Your construction company is required to make an exact three-dimensional model of the structure, but will only have access to color-coded instructions. Considering this constraint, you decide to send the company Foreman to view the plans. The Foreman will report back to the contractors to describe the model so that the remainder of team can duplicate the structure from his/her instructions.

## The Limitations:

- Your team will have one class period to complete this challenge.
- Each team is responsible for selecting its own Foreman (the only team member permitted to view the original instructions/plans.)
- The Foreman may make as many visits as needed to view the plans.
- The Foreman may only use verbal skills to communicate to the contractors. They may take notes and make drawings but they may not allow their team members to view these items.
- The Foreman must keep his/her hands *behind him/her at all times when talking with their team members.*
- The Contractors (remainder of team) are in charge of constructing the model based upon the Foreman's verbal directions.
- Only the Contractors may touch the building materials.

## The Rules:

- All members of the construction team must be actively engaged.
- Your team must provide a complete budget report detailing the cost of the model using the K'NEX Cost Sheet.
- At the conclusion of this challenge, *each team member* must individually write a report to Mega Clean Air, Inc. describing:
  - \*Their role in the communication process.
  - \*How they felt during the challenge and why they felt this way.
  - \*What they would change if they had to repeat this process at another time.
  - \*What they would do differently if they were to change roles.
  - \*What suggestions they could offer to make the communication process easier.
- Keep track of your construction time to compare with other groups who may complete this activity later.

# THE WONDEROUS WINDMILL



## Costruction Conundrum

### K'NEX COST SHEET

Connectors	Cost	Rods	Cost	Other	Cost
White	\$1.00	Long Gray	\$2.45	Blue Spacers	\$ .23
Blue	\$ .90	Long Black	\$3.98	Silver Spacers	\$ .47
Gray	\$ .90	Red	\$1.83		
Red	\$ .75	Yellow	\$1.03		
Yellow	\$ .68	Blue	\$ .78		
Green	\$ .41	White	\$ .56		
Silver Blue	\$ .36	Green	\$ .34		
Purple	\$ .24				
Tan	\$ .11				





# Student Response Sheet

# 7

Name: \_\_\_\_\_

Date: \_\_\_\_\_



The windmill you redesigned during the last activity performs very well but it still only makes the vertical arm of the system move up and down. Work with your team and make changes to your windmill so that it is able to complete some task (i.e., move, lift, drag, push, or pull something). Your teacher will provide materials that you may use in addition to remaining K'NEX pieces to complete your redesign.

**Draw a sketch of the Mechanical System you Designed**

- Demonstrate the operation of your newly designed windmill to the class.
- Does the addition of a task to the windmill system decrease the performance of the windmill? How do you know? What did you do to test the performance?
- What was the biggest challenge that your team faced as they attacked this redesign activity?

**THE WONDEROUS WINDMILL**

## Lesson 7

# THE TOWER CRANE

### Objectives:

The students will be able to:

- Identify and investigate variables associated with specific structures
- Modify the design of the tower crane for investigative purposes
- Evaluate the effectiveness of design modifications
- Collect, organize, graph and interpret investigative data

### Materials:

- Engineering Marvels: Buildings, Structures and Machines Set
- Several rolls of pennies or a collection of large washers
- Several 3.5 oz cups
- Metric tape
- String
- Two spring scales
- Graph paper
- Copies of **Student Response Sheet # 8**
- Copies of the **History of the Tower Crane** reader
- Copies of **Student Response Sheet # 9**

### Total Anticipated Time Frame:

Seven to nine 45-50 minute class periods at the discretion of the teacher

### Models:

- One group of students can build the Crane model for this lesson while another group builds the Flying Buttress model and completes Lesson 2

### ENGAGE:

Ask students to describe what they think a tower crane is. After some discussion, distribute building instructions for the K'NEX tower crane for the students to use as a reference. Where have students seen cranes like this in the past? What purpose do cranes like this serve? Explain to one student group that they will form a team to build a tower crane model that they will use for a series of activities. The first challenge for the student teams is to plan a construction strategy that will be both fast and efficient. Provide time for the students to discuss how they will accomplish the task at hand in as little time as possible while including every team member.

Time Frame approximately 25 minutes

### EXPLORE:

Once the students have decided on an assembly process, provide access to the materials and allow them to begin building the cranes.

Time Frame approximately 45 minutes

### EXPLAIN:

The students will respond to the following writing prompt: "Three main points that I learned about while completing our task were..." When the students have completed their reflective writing assignment ask them to discuss and evaluate their strategy. Ask them what procedures they would keep the same, what would they change and why? In what ways could they possibly improve the efficiency of this process?

Time Frame approximately 45 minutes

# THE TOWER CRANE

## Lesson 7

### EXPLORE:

#### • Part # 1:

- \* At this point, your crane does not have a cable system and crank to lift materials off of the table top. The first portion of students' exploration will be to investigate the importance of balance in a tower crane system. Provide students with copies of **Student Response Sheet # 8** and review the directions with them. Students will need pennies, metal washers, or other masses for this activity (small dense masses work much better for this activity than large masses).
- \* Students will discover that the tower crane system is stable when it is in balance and that the base of the crane system is important to keeping the machine standing.
- \* Their investigation will help them to realize that mass added to the side of the boom that holds the counterweights will balance the crane when it is lifting a large load.
- \* At the conclusion of the activity students will need to answer one additional question about their investigation. (The question is not on **Student Response Sheet # 8** so it does not influence the investigations students are completing.)
  - How would you describe the relationship between the mass required to balance the crane and the mass of the object that is being lifted?
  - Students should respond that it requires more mass to balance the system than the mass being lifted. The explanation should relate this to the uneven lengths of the arms on the boom and possibly to the science of levers and mechanical advantage.

Time Frame approximately 45 minutes



#### • Part # 2:

- \* Inform students that they are going to redesign their models so that they can use them to lift items off of the surface of the table. Instruct them to make modifications to the model so that it can raise objects suspended from the end of the long arm of the crane. Make the students aware that there are pulleys, string, and various other K'NEX parts for them to use in the K'NEX storage tray.

Time Frame approximately 45 minutes



- \* Provide students with copies of **Student Response Sheet # 9** and challenge the students to create a 1/5 technical/scale drawing (1:5) of the crane they have redesigned. Have the students label their drawing and record the assumed function of each crane component. Students will need access to research materials to complete the questions on the sheet.

Time Frame approximately 45 minutes



- \* Challenge students to explore their crane and to confirm or refute their assumptions about the function of the crane components. Tell students that they need to collect quantifiable data whenever possible. For example, if they believe that the support ties that run from the end of the boom to the top of the crane serve to support and keep the boom level, then removing them could result in a *measurable* "sag" or deflection of the boom.

Time Frame approximately 20 minutes



**EXPLAIN:**

As a formative assessment, require students to write a reflective letter to a friend explaining how a tower crane works. This direction is provided to students as the last section of **Student Response Sheet # 9**.

Time Frame approximately 45 minutes 

**ELABORATE:**

During this lesson phase it is anticipated that students will select several crane options to investigate from the following suggestions, or one or more will be assigned by the teacher. The time required to complete these investigations is dependent upon the extent of student involvement.

**Option 1**

- Your crane has been erected at a construction site, but the boom is not long enough to deliver materials to the opposite side of the building (a dimension in your scale of 22 cm). Modify your crane to solve this problem.
- Be sure to describe your plan and what measures you will take to ensure that the boom remains level.

Time Frame approximately 45 minutes 

**Option 2 (Two Part Challenge)**

- **Part #1:**

Your company has to modify the tower crane to lift 200 grams while keeping the boom arm level. Describe how you will accomplish this task.

However, just as you accomplish this task, an incredibly huge air conditioning unit arrives on the job that is twice that mass. Adding more counterweight to the boom arm is not recommended, thus an alternative solution must be sought to lift a mass of 400 grams while not compromising the stability of the crane.

- **Part #2:**

Describe what you plan to do, draw a sketch of your plan, summarize and explain your results in terms of the science and technology concepts that drive your decision.

Does the height of the tower section above the boom make a difference in the stability of the crane? Design and conduct a “fair test” to answer that question. Describe your procedure, your test, and your results.

What is the predominant architectural shape found throughout the crane? What other structures have you investigated that use this shape? Why do you think this shape is so common in the superstructure of your crane?

Time Frame approximately 45 minutes  

### EVALUATE:

The final phase of this investigation is a blend of student research, hands-on investigations and data interpretation. Students may be instructed to complete all or any combination of these options based on time constraints and curricular needs.

### STUDENT RESEARCH AND INVESTIGATION:

#### Option 1:

How do you think tower cranes “grow” taller? Research this question and provide a written response. Why is it necessary that a tower crane be able to “grow” taller?

#### Option 2:

Complete a research project based on the following questions:

How is your tower crane like other kinds of cranes? How is it different?

What components do all cranes have in common?

Historically, how were the earliest cranes used?

What evidence is there of these early cranes?

#### Option 3:

Use the K’NEX, and other materials, to build models of other types of cranes and demonstrate how they function.

#### Option 4:

Use a spring scale to find the mass of a roll of pennies in Newtons. Attach these pennies to the end of the crane’s cable. Attach the spring scale to the crank and determine the force, in Newtons, required to lift a roll of pennies. Why do you think there was a difference between lifting the pennies with and without the crane? Explain your answer in detail and provide a sketch of the system you tested.

Suppose your crane has to lift a load that is twice the mass of the pennies without increasing the effort required (in Newtons).

Describe how you think you can accomplish this task.

Provide a data display of your results.

Tell why you think your modifications were, or were not successful.

Research the term mechanical advantage & apply that in the explanation of your challenge.

Time Frame approximately 45 minutes





# Student Response Sheet

# 8

Name: \_\_\_\_\_

Date: \_\_\_\_\_

## THE TOWER CRANE

### A mechanical system in balance:

- Read the **History of the Tower Crane** to gather background information for this activity.
- Make an adjustment to your crane model in order to test its balance. Notice the yellow and red rods at the bottom of the tower that form a base. As one of your team members holds the tower off of the ground carefully unsnap the red rods from the side of the tower and unsnap the yellow rods from the point where they meet the tower. You should now be able to pull away the base of the tower as a single unit. Set aside the base and place the tower on the table.
- Is your tower crane balanced? How do you know?
  
- If you push down gently on the long end of the tower crane system, what happens to the crane? (Caution: Do not let the crane fall.)
  
- What potential problem might this present in a real life situation when something like a 4 ton air conditioning unit must be lifted with the crane?
  
- As one team member applies gentle pressure down on the top of the crane to hold it in place, add mass to the cup at the end of the long boom section. Ask your team member to carefully pull their hand away to see what happens. (They should be ready to grasp the crane if it begins to fall.)
- Based on what you have read about the tower crane and your own knowledge of simple machines, propose a simple way to support the mass at the long end of the crane so your team member does not have to hold their hand on the crane to keep it from falling. Describe your solution.
  
- Test your solution. Were you successful? Explain.
  
- Your teacher will provide an additional question for you to answer about your crane. When you have investigated that question, you may reconnect the base to your crane.



## Observing the Tower Crane:

- Redesign your model as directed by your teacher to enable it to lift objects from the table top. As you work, add a crank system to the model so that you can raise an object by turning the crank.
- Use a metric tape and a piece of graph paper to create a 1/5 (1:5) technical/scale drawing of your newly redesigned tower crane in pencil.
- Circle what you believe to be the major parts. Next to each major part write a brief description of the purpose you believe this part serves.
- Use color to help identify the major parts of the crane.
- Explore the component systems of the crane to determine what purposes they might serve. If possible, support your ideas with measurable data.
- Your teacher will allow your team access to resource materials that will enable you to research the tower crane and finalize your drawing.

## Explaining the Tower Crane:

- Based upon your observations and investigations, write a reflective letter to a friend explaining how a tower crane works.



# Lesson 8

# ENGINEERING DESIGN PROJECT FLASHBACK, GATEWAY TO THE WEST

### Objectives:

- Students will be able to:
- Work effectively in collaborative teams
  - Design a plot plan for an urban renewal project
  - Assume the roles of various engineers for the duration of their project
  - Create a technical/scale drawing of a designed plot

### Materials:

- For each student team
- Engineering Marvels: Buildings, Structures and Machines Set
  - Measuring tapes and rulers
  - Team supplied materials (Optional)
  - Crayons/markers/colored pencils
  - Copies of the **Engineering Design Brief**
  - Copies of the **Flashback Development Area Map**
  - Copies of **Development Occupations**
  - Copies of the **Engineering Design Brief Rubric**
  - Two copies each of the five **Engineering Occupations** reader pages
  - Large pieces of cardboard (90 cm X 60 cm or larger)
  - Large sheets of drawing paper (90 cm X 60 cm or larger)

**Time to Build:**  
15 minutes



**Length of Lesson:**  
2 x 45 minutes



### Total Anticipated Time Frame:

Seven to eight 45 minute class periods at the discretion of the teacher with options to extend the activity even further

ENGINEERING DESIGN

### Teacher Notes:

*This design brief was developed as a general engineering brief, but can be used for a variety of other purposes. For example, some students at the middle school level may still have difficulty in creating an overhead projection (i.e., aerial view site plan) and as a result may also have difficulty reading and interpreting maps. An activity like this could prove helpful in identifying these students. Other applications center on art, measurement, conservation, environmental/human impact and translating two-dimensional sketches into a three dimensional models. Finally, it is expected that students will present their designs in an open forum. This provides an opportunity for students to field questions and defend their designs.*

*This design brief requires the students to demonstrate the correct use of process skills and collaborative group structures while investigating the architectural relationship between the form and the function of a design. The tenet of **form following function** is true not only for manmade structures, but also for the structure of living organisms and often becomes obvious when it is **not** properly applied rather than when it is. For example, the ergonomically correct design for the interior of a car is an expectation for passengers. However, when the design is inappropriate, when the form of things such as switches, seats and so on does not properly reflect their function, it is noticeable, annoying and reflective of improper engineering.*





# ENGINEERING DESIGN PROJECT

## FLASHBACK, GATEWAY TO THE WEST

### Lesson 8

#### ENGAGE:

Read the following to the students.

*The creation of most structures involves the cooperation and input from a number of associated occupations. The idea for a structure sometimes arises from need, such as the necessity for a bridge, and sometimes the structure is created to signify a special event, a famous person or place. Designers and architects first create two-dimensional technical drawings and illustrations. Generally, the architectural interpretations are considered and discussed by those who will fund the project. At this point, three-dimensional, scale models are often created to demonstrate what the final structure might look like. Once a design is approved, it is often necessary for city/site planners and environmental engineers to review the plans to determine how the new structure will fit within the existing area, keeping in mind the impact the structure will have on the environment. After all parties are satisfied, and the necessary land acquired, construction generally begins.*

*Your assignment will be to create a structure of some kind based on the scenario in the Engineering Design Brief. Each member of the team will have one, or more, responsibilities. As a team you must first decide what kind of structure will be built and provide a rationale for its need. Before the construction begins city/site planners have to create a “footprint” or plot plan of the general area surrounding the structure. This top view plan must allow for traffic flow, parking and so on.*

Distribute copies of the **Engineering Design Brief**, the **Development Occupations**, and the **Flashback Development Area**. Have students read over all the materials. Then ask them to gather in their work teams and discuss what they perceive to be the task at hand. Ask the students to share their perceptions. This formative assessment will provide immediate feedback regarding the level of student understanding.

Time frame approximately 45 minutes



#### EXPLORE:

When you are assured that the students have a handle on the assignment, allow them to begin. It is suggested that a reasonable timeline and completion schedule be established so that the students will be more likely to stay on task. For example, at the completion of the second class period, students should have completed a rough copy of their plot plan and have a basic design of the structure.

#### Teacher Note:

*The time frame for the remainder of this lesson will vary depending upon the structure set by the teacher. This is a long range assignment, somewhere in the range of six to seven class periods, and progress check points should be established to ensure the students are on track*

#### EXPLAIN:

This component could be conducted as a full class discussion by having the students share their progress a number of times throughout the term of the project. Another approach would be to visit each group individually to assess progress and to provide guidance where necessary.



## Lesson 8

# ENGINEERING DESIGN PROJECT FLASHBACK, GATEWAY TO THE WEST

### ELABORATE:

During this phase students will use the **Engineering Design Brief Rubric** as they present and evaluate their projects. These rubrics also allow the class to evaluate presentations.

### EVALUATE:

This project provides an opportunity for self and peer evaluation through the students' application, and adherence to, the rules and limitations. In addition, the overall assignment gives teachers an opportunity to evaluate the collaborative work of groups and individual students throughout the course of the assignment.

### EXTENSION:

Design a board game that reflects the inter workings of the people and the problems associated with the development of a new structure. Additional information to guide students in the development of a board game is found at the end of this section.



(Adapted from *Inquiry by Design*, Gooding & Metz, 2006 with permission of the authors.)

## The Context:

Building a structure requires careful planning, coordinating many different occupations, and coming to grips with hundreds of problems.

## The Scenario:

The Midwestern city of Flashback, nestled on the banks of the Navaho River, is contemplating the construction of a large structure in tribute to the brave men and women who crossed the Great Plains in covered wagons. Flashback is not a wealthy city, and while it supports the idea of creating a tribute to the founding fathers, it needs to be practical as well. Whatever structure is created needs to be multipurpose and environmentally sensitive (green).

## The Challenge:

Your engineering team has been challenged to create rough drafts for the six-block waterfront area of the city, and the proposed commemorative structure and park. Teams should also address possible environmental and human impact issues before construction begins. Final versions of the plot plans must be completed prior to the final presentation. You and your partners must pick up a packet containing descriptions of the occupations (roles) and a copy of the existing riverfront. Although the land is free, your team must develop it in a specific way.

## The Limitations:

- Each team will have five or more class periods, at the discretion of the teacher, to complete its plot development and present the development proposal.
- Students may work outside of class on this project.
- While team members will each have specific roles to play, *members may assist other members as they complete a task*. Refer to the **Development Occupations Sheet** and assign the various roles to members of your team.
- Your teacher will provide copies of **Engineering Occupations** sheets that will provide additional information about the occupations you have been assigned.
- The city has granted six blocks along the river for development (600 meters X 400 meters).
- Each team should incorporate natural features into their plan during the design process.
- Each team should use the Engineering Design Brief Rubric as a reference as they craft their presentation.
- The park design should allow for the smooth flow of pedestrians from one place to another, keeping in mind such things as parking and vehicular traffic.



# Engineering Design Brief

### The Rules:

- Teams may bring in additional materials for their project if they so desire.
- All plot plans must:
  - Be drawn to scale. The scale must be noted.
  - Be no smaller than 90 cm X 60 cm (actual size)
  - Include a legend
  - Include three-dimensional K'NEX models of structures and landscaping made from cardboard or other materials supplied by your team or teacher (cardboard should be available to support the scale drawing and models).
- Each team must document all research references they used during this project.
- All teams must show evidence that they addressed environmental issues and problems that could have occurred during construction.
- Each team will use the Engineering Design Brief Rubric as a rating tool.

# Engineering Design Brief Rubric



*(Adapted from Inquiry by Design, Gooding & Metz, 2006 with permission of the authors)*

	4	3	2	1	Team Evaluation Score	Class Evaluation Score
<b>Structure Requirements</b>	The structure meets size requirements and has three different "green" systems* included.	The structure meets size requirements but does not have three different "green" systems* included.	The structure only meets one of the size requirements and has some "green" systems* included.	The structure does not meet size requirements and has not included any "green" systems*.		
<b>Use of Natural and Human Made Features</b>	The natural and human made features have been incorporated into the design.	Some of the natural and human made features have been incorporated into the design.	There has been minimal attention paid to the natural and human made features into the design.	The natural and human made features were not included into the design.		
<b>Visitor Accommodations</b>	The designed appears user friendly for all groups regardless of age, size or special need.	The design is generally user friendly but has not accounted for all age groups.	The design focuses on only one age group and is lacking in some accommodations	The design is limited in its design and as such will only appeal to one healthy age group.		
<b>Traffic Patterns</b>	Visitors can expect many transition points into and out of the area and parking lot. The design allows for easy access to all sections.	Visitors will find only two transition points into and out of the area. The design allows for access to most sections but bottlenecks have been created.	Visitors can expect some difficulty getting around the area. The design does not allow for access from everywhere.	Visitors can expect to have difficulty with parking and access to the area. The design does not allow for access to most sections.		
<b>Plot Plans</b>	All plot requirements are present. The plot legend/legends is/are easy to read with appropriate use of symbols, color and scale. The entire plot is presented using the top view.	Most of the plot requirements are present. The plot legend/legends is/are in color and contain some symbols. Most of the plot is presented using the top view.	Most of the plot requirements are present. The plot legend/legends is/use some color but symbols are not generally used. The plot is presented using a variety of views.	Many of the plot requirements are not present. The plot legend/legends is/do not use color and symbols are not generally used. The plot is presented using a variety of views.		
					<b>Total Score</b>	

\* Green systems include such things as solar energy, reflective glass, rooftop gardens, insulation, water and other recycling systems, and so on.

## ENGINEERING DESIGN



## Development Occupations

### ENGINEERING DESIGN

**Frank Floyd Light – Architect:** Your architectural firm has been selected to serve as the architect/designer for the new structure. The City Council has given you the following guidelines to help in the design process. The structure must be a minimum of 300 feet high, and be very unique in its design...reflecting the pioneers in some easily recognizable way. In addition, you also need to design this structure to serve more than one use. Two of the six riverfront blocks will be used for the construction of a parking facility.

**Wilson Wackerton – City/Site Planner:** As the city/site planner you are responsible for the general footprint (plot plan) of the entire six block area. You must work closely with all other occupations since they are responsible for making your plan come to life. Your drawing must be to scale, in color, employ symbols and contain a legend. You must be concerned with present traffic flow, parking facilities, how the new structure will impact the environment and the present community. You must balance the need for the structure and the possible business benefits with the improvement to the community and to the quality of life of all who live there.

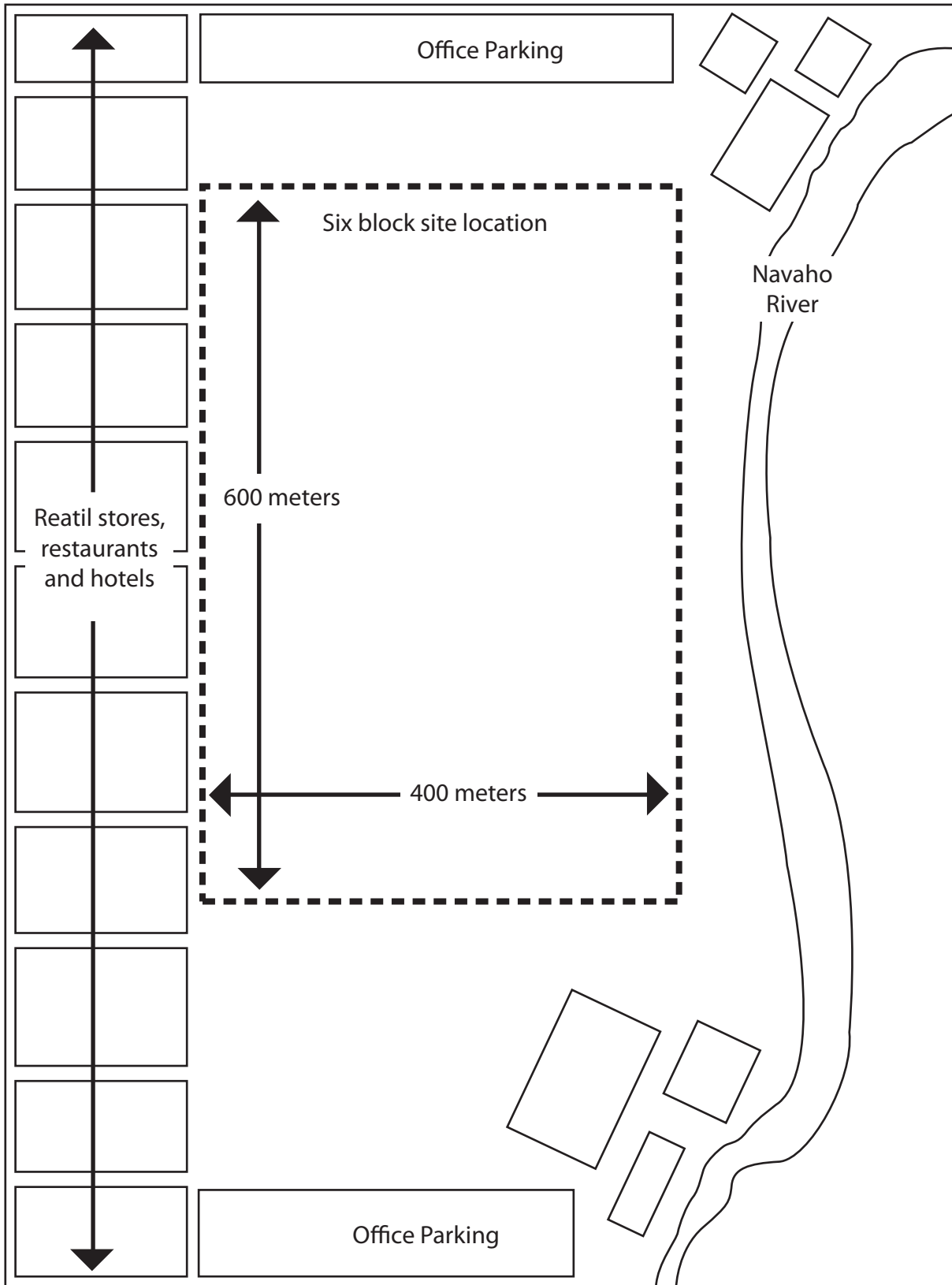
**Kermit Green - Environmental Engineer:** Every human action has an impact on the environment; and building a large structure generally brings potentially large environmental issues with it. But what exactly are these issues? Your first responsibility will be to research what environmental problems might occur at a major construction site and how these issues are resolved. In addition to environmental issues that arise during your own research, you need to consider the following: How is the dirt from excavation prevented from washing into the river during heavy rainstorms? How is trash from the construction site handled in an environmentally safe manner? Is the building a “green” structure? What measures have been taken to reduce the building’s energy demands?

**Rocky Steel - Materials Engineer:** As a practicing scientist, your responsibility is to develop new ways to use common materials and/or find materials that can be used in unique ways. An example would be the newspaper tower you built earlier. By rolling newspaper into tight tubes, you were able to increase its strength. The City Council is very interested in increasing the tourist trade in Flashback. Toward that end, they have decided that a unique use of materials is a critical factor.

**Bruce Force - Structural Engineer:** Making certain that all structures meet current codes is one of your responsibilities. While the architect’s rendering may look good, it must also be strong enough to withstand the most severe weather conditions for that region. An additional responsibility lies in the selection and use of the materials chosen for the structure.

**Garbanzo Construction Company:** Your company has won the bid to construct the three-dimensional/scale structure that the architect, Frank Floyd Light, designs. You are also dependent upon Rocky Steel to suggest appropriate materials or a unique use for those materials. Your time is limited so organizing your materials and your sub-contractors is absolutely essential.

# Flashback Development Area Map



**ENGINEERING DESIGN**



## Optional Activity

### Designing a Game Board Suggestions and Stipulations

(Adapted from *Inquiry by Design*, Gooding & Metz, 2006 with permission from the authors)

Your design team has been challenged to create a board game that deals with the process of designing and constructing a structure.

- Each team will have five class periods to complete this challenge at the discretion of the teacher.
- Team members are encouraged to work on this project at home.
- Each team should research existing board games as a comparative data gathering process.
- Detailed directions of the rules, including how to determine the order of play, must accompany the game.
- The game must provide some way of identifying each player.
- The game must have a way for players to advance (spinner, die, random drawing, etc.).
- The game must provide opportunities for the players to make choices on their own or have those choices made for them by virtue of rolling a die, choosing a directional card (choice, reward or consequence, for example) or some other random/chance method.
- The game should have a clearly marked route for the players to follow with a START location noted.
- The rewards must be equal to the consequences (see detailed notes for further explanation).
- Each team must play and evaluate the games of others teams.

#### **SUGGESTED MATERIALS:**

Provide students with an opportunity to compare and contrast a number of board games either at home or in school. This will enable them to form an “idea bank” upon which to draw while constructing their own games.

This challenge requires the students to apply the information they gained as a result of researching and conducting the Engineering Design Brief. As noted, the five days set aside for this challenge are at the discretion of the teacher, and as such, provide “wiggle room” to allow students sufficient time. These five days can be scattered throughout a marking period to provide students sufficient “research and development” time.





There are several components associated with this activity. Some requirements are team oriented while others are designed for individuals. In either case the time students spend on each phase needs to be managed. It is suggested that a schedule be created and posted to help keep students on task. Initially, students will need to become familiar with the commonalities between board games, the methods that are used to identify the players, what determines the order and extent of player moves, the trade-offs associated with decision making, and so on. This “game research” phase will also provide students with the background that they will need to develop their own game board.

### **GAME BOARD DETAILED NOTES AND OPTIONS**

#### **Risks and Consequences:**

Player risks should be comparable to player consequences. The greater the risk taken by a player the greater the potential gain or consequence. For example, if a shorter route is available to a desired location or reward, the probability of a major setback should also be present.

#### **Risk and Consequences Cards:**

Similar to the CHANCE and COMMUNITY CHEST from the Monopoly™ Game, these are available only to those players who land on a particular spot on the game board. These cards should be color coded either by font color or printed on different color stock. A few sample generic cards for this activity are provided on the following page. It is suggested that the students be given the challenge of creating additional cards on their own.



# Optional Activity

## Sample Risk and Consequence Cards

Your concrete order does not arrive on time. Lose a turn.	The City Council doubles the cost of your building permit. Lose a turn.	A winter storm shuts down your project for three days. Lose three turns.	The steel company sent the wrong reinforcing materials. Lose a turn.	A labor strike is over. Your company takes an extra turn.
The solar panels installed on the roof are working better than expected. Take an extra turn.	Your backhoe operator hits a gas line while digging a trench. Lose a turn.	The City shuts down the site because of a toxic materials leak found during the excavation. Lose two turns.	The community is generally pleased with your plans to include a senior center. Take an extra turn.	The Visitors Center wins an award for innovative design. Take an extra turn.
The city planner forgot to include public bathrooms in the recreation area. Lose a two turns.	The roof leaks. Lose a turn.	Core samples of the concrete show that it is stronger than needed. Take an extra turn.	The lighting system has come under criticism because it is not as energy efficient as other lighting systems. Lose a turn.	The weather remains clear and dry. Windows are installed ahead of time. Take an extra turn.
Someone ordered the wrong plumbing fixtures. Lose a turn.	The water recycling system works as planned. Take an extra turn.	The architect quits over a disagreement with the City Council. Lose a turn.	Your building plans run into some opposition from a local environmental group. Lose a turn.	The entrance to the underground parking lot is too short for large SUV's. Lose a turn.
Additional sponsors are found to support the project. Take two extra turns.	The environmentally friendly brick cycling paths were paved over. Lose three turns.	The elevator shafts were made smaller than the elevators. Lose two turns.	The design is an instant success and tourism is sure to increase. Take an extra turn.	The light-weight cement mixture is performing much better than predicted. Take two extra turns.
The carpet used in the structure is made from recycled plastic bottles. Take an extra turn.	The structure includes a child care and a health care facility. Take three extra turns.	The structure is unstable in high winds. Engineers must design a way to reinforce the structure. Lose two turns.	The city planner has included walking paths in the area surrounding the structure. Take an extra turn.	Cost overrides halt the construction for two weeks. Lose a turn.
The city planner has included a fitness course as part of the park. Take an extra turn.	The play areas in the park are paved with recycled tires. Take an extra turn.	The rough construction is completed on time and under budget. Take two extra turns.	The designer changes the color scheme after the walls have been painted. Lose a turn.	The City Council delays the opening of the structure because it is arguing over what it should be called. Lose a turn.
Plants covering the rooftop will significantly decrease energy consumption. Take an extra turn.	The structure faces south and this allows for passive solar radiation. Take two extra turns.	The ground for the foundation is loose fill and needs to be stiffened with deep concrete pilings. Lose one turn.	Installing a sprinkler system, smoke alarms and CO2 detectors reduced your insurance costs. Take an extra turn.	An archeological site was discovered when the site was excavated and construction was delayed. Lose two turns.

## Optional Activity



### **REWARD AND PROBABILITY:**

The size of a reward should be indirectly related to the probability that a player would be able to achieve that reward. For example, a large reward could be received only if the player, using three dice, was lucky enough to roll the same number on all three dice.

### **CONCEPTS AND ISSUES:**

The intent of the game is to highlight those issues, problems, occupations and engineering strategies associated with the creation and development of a structure. During the course of most projects numerous problems occur. These issues could be related to human interaction, material performance or accessibility, environmental oversights or actions, engineering successes or failures and any number of other unexpected predicaments.

### **GAME OPTIONS TO CONSIDER:**

- The opportunity for players to “barter” with each other might be part of the game.
- A timing device might be used in some way.
- Randomizing devices such as die and spinners might be used in combination.
- Drawing choice or consequence cards might be used.
- Players might be able to penalize each other in some way.
- If dice are used, rolling doubles may be considered a positive or negative occurrence.
- A bag of different colored marbles could be used as a choice option. The color drawn by a player could then be a reward or punishment depending on the rules of the game.

# SEVEN HISTORICAL PERSPECTIVES

## THE IMPORTANCE OF FAILURES

What role does failure play in the advancement of engineering? A very important role since we must continually learn from our mistakes and the mistakes of others. Each time a building, tower, bridge, etc. fails there is an opportunity to investigate the failure and determine the cause. Substandard building materials, weak foundations, construction shortcuts, and structural fatigue have all contributed to engineering failures more than once over the years. It is of utmost importance that the engineers of today are ever vigilant as they inspect structures to ensure that they are sound and to work on new structures to make them strong and useful.

In most countries around the world, engineers follow strict building codes that prescribe the rules that must be followed in construction to ensure the safety of the public. Additionally, most countries have rigorous inspection procedures in place to examine public structures on a regular basis to ensure they remain safe. In other countries those codes are less than we would hope and those countries suffer many more structural failures than normal. When an engineering disaster does happen somewhere in the world, the international engineering community offers

assistance to investigate the disaster and offers recommendations to avoid similar problems in other buildings and structures. A few years ago a bridge collapse in Minneapolis, Minnesota led state governments around the United States to immediately inspect all similar bridges in their own communities. The Minneapolis failure sounded the alarm and engineers around the nation began the process of inspection to ensure the safety of the driving public across the country.

One of the most famous structural failures occurred in 1940 when the Tacoma Narrows Bridge collapsed. The Tacoma Narrows Bridge was a very narrow suspension bridge that had been designed and constructed with little attention to the winds that the bridge would be exposed to in the Tacoma area. As strong winds passed simultaneously over the top and under the bottom of the deck the surface would regularly rise and fall in rhythmic fashion. Drivers who used the bridge often soon named the bridge 'Galloping Gertie' in response to their experiences driving across the bridge. One day in 1940 the rise and fall of the road deck grew very severe and the bridge deck appeared to move in waves across the length of the span. Drivers were unable to continue across the bridge and they abandoned their cars and walked off the bridge by walking





along the lane lines that separated the traffic. The lane lines were the one location on the bridge where the motion was least severe. The concrete and steel of the road deck could no longer stand the forces of this motion and the deck broke into sections and fell into the river. An Internet search of the Tacoma Narrows Bridge will provide access to film footage of the harmonic waves that moved along the bridge, and its collapse.

As a result of the Tacoma Narrows collapse, suspension bridges and suspension bridge designs were meticulously investigated to avoid similar disasters. The driving public was concerned about its safety and fast action was required from state governments and engineers across the country. Some bridges were quickly closed until testing and repair work could be completed. As a result of the Tacoma Narrows disaster, suspension bridges across the country became safer. Some were outfitted with stronger deck supports, others received specialized wind deflectors to lessen the impact of the wind, and still others (like the Brooklyn Bridge) were strengthened with support cables that reduced deck movement.

Structural failures and disasters have happened for centuries and they continue to happen even today. Buildings fall down, tower cranes collapse in big cities, parking garages collapse, and even large arenas and stadiums have experienced partial or total collapse. Immediately following a collapse, the investigations begin. When the causes have



been identified, structural engineers can begin the process of testing and securing similar structures. Other structural engineering specialists begin the process of changing designs, construction materials and construction techniques for structures still on the drawing board. The goal is to learn from failures and to improve the safety of future buildings and structures.

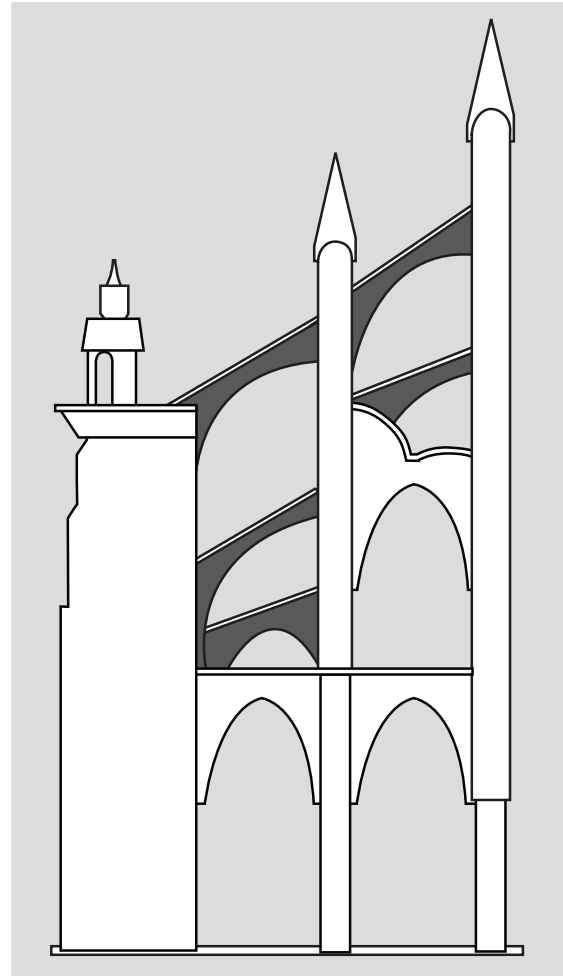
## HISTORY OF THE FLYING BUTTRESS

**M**aking changes in the way we do things is sometimes a difficult task. The same held true in medieval times when it came to the construction of buildings both small and large. There was plenty of stone, mortar, and wood for building and the construction techniques that had been used for centuries were still being used. The stone walls of small buildings could be thin, but the walls of tall buildings needed the strength and support of thick walls. This fact is especially noticeable in the castles of this time period. Times and construction techniques were about to change as needs changed.

The tall thick-walled structures of the time period served their purpose but they did have limitations. Window openings had to be small so the walls could maintain their strength and thus little natural light was able to enter tall towers, castles, or buildings. Additionally, as buildings grew taller and thus more massive, they needed stronger and stronger foundations to ensure they did not lean or fall.

Proud townspeople, city officials, and the clergy in cities and towns across Europe wanted taller and more impressive churches in their communities. These taller churches were to have grand, tall windows and high arches to allow unobstructed views to the ceiling. In that time period and even to this day, bigger construction was always considered better. Each city or town wanted the tallest possible towers, buildings, and especially churches to demonstrate the prestige of their town and skill of their tradesmen. The massive buildings of the past were not going to be able to meet these new requirements for tall windows and high ceilings. A change would have to be made in building materials or construction techniques if these new taller churches were to become a reality.

It was the construction techniques that changed. A new construction strategy came into prominence that allowed churches to be built taller with large windows and high ceilings. The innovation was the flying buttress. This structure allowed the forces acting on the thin walls of a tall church to be transferred to a series of pillars



or towers some distance from the wall. With the forces lessened on the walls, they did not need to be thick and larger windows could be added. Additionally, the extreme forces placed on the walls by high arched ceilings could also be transferred away from the walls. A single solution was going to solve several construction problems.

Master builders of the 13<sup>th</sup> century had several construction techniques that enabled them to build high arched ceilings like those in the photo on the following page. These high ceilings were made possible using various vaults that were breathtaking but they placed great, outward forces on the walls that supported them. The accepted technique to counter these forces was with the use of thick stone walls. With the advent of the flying buttress the outward forces from the vaults were transferred away from the walls and directed safely into the ground.



As you observe the drawing at the top of the previous page, the wall of the church is on the right side and there are two support pillars. One support pillar is in the center of the drawing and the other is on the left side of the drawing. The arched, stone connections between the pillars and the building are called flyers and they transfer force from the building to the pillars. The use of two pillars added to the strength of this flying buttress system and allowed it to support higher walls than a single pillar system. The flyers were a construction challenge for medieval masons. Carpenters constructed wooden arches to extend from the pillars to the building and the masons constructed stone arches above them. When the mortar was cured on the stone arches, the wooden support forms were removed and used to provide a platform for another flyer to be built.

The design and construction of flying buttresses during the medieval period were not exact sciences and some of them were more successful than others. Many of the Gothic churches built using this technology are still standing due to the precise geometry of the flyers and their placement against the church walls. Some less geometrically stable flying buttresses have been redesigned and rebuilt over the centuries. Modern engineers who have investigated the geometry of some of the ancient flying buttresses have discovered that they demonstrate exceptionally precise geometry that would be difficult to surpass today.



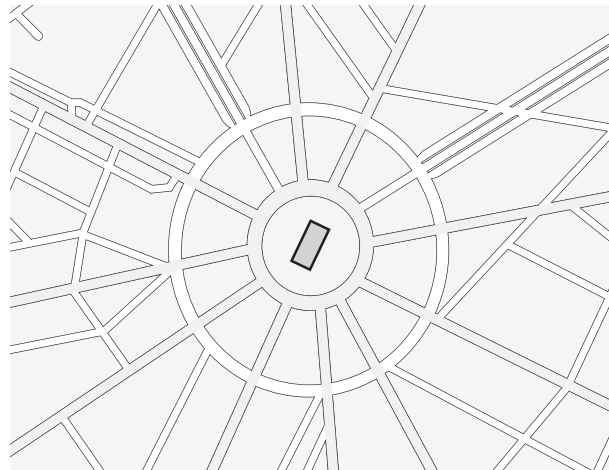
The flying buttress is only one of the many types of buttresses that have been used for centuries to support and strengthen the walls of buildings and towers around the world. Flying buttresses, other buttresses and the various types of vaults that formed the ceilings of Gothic churches are very interesting topics for research and reporting. The Internet and many engineering books available at the library will provide the necessary resources for your research.



## HISTORY OF THE ARC DE TRIOMPHE

Throughout history humans have created large structures for a variety of purposes. Some of these structures were built to celebrate an event, some were erected to glorify a person and some were designed to serve economic purposes. Whatever the reason, the challenge to build the biggest or tallest structure seems to have been part of the motivation. The Arc de Triomphe in Paris, France was no exception. When it was built in the early 19<sup>th</sup> century, it was one of the largest man-made structures of its kind in the world. Today, the Arch of Triumph in Pyongyang, Korea is larger. The Arc has remained unchanged since it was first built although a tomb to honor unknown soldiers who fought for France was added below the structure in 1920.

This 162 foot tall, 145 foot wide structure was the vision of Napoleon as a way to honor the French armies. Originally, the Arc was centered at the top of a hill in the middle of a wide grassy area, the Champs-Elysees. Although the Arc has remained unchanged, the area around the Arc has become congested with traffic as 12 avenues and streets converge on the roundabout (traffic circle) that encircles the Arc.



Napoleon envisioned the structure to be a centerpiece in the capital city of France and to that end had numerous access paths radiating out from this central location. Those paths eventually became the roadways we find extending out from the Arc. When viewed from the air, these streets resemble the spokes of a wheel. Several map programs on the Internet provide aerial view drawings of the region surrounding the Arc and some also include the option to view an outstanding satellite image of the area including the Arc. In order to protect tourists and local visitors who travel to see the Arc, underground passageways have been added to the area to enable people to travel safely under the traffic as they make their way to the Arc.

It is very hard to imagine the size of the Arc just by looking at pictures in a book or on the Internet. There is very little around the Arc to provide any frame of reference that the observer can use for comparison. One vivid example of the size of the Arc was provided after World War I. A French Air Force pilot flew his plane through the Arc to honor his fellow pilots who were killed in the war. The fact that such a feat was even possible should make everyone more aware of the size of this famous French landmark.





## HISTORY OF THE FIRST IRON BRIDGE

Throughout history there are many examples of instances where a series of serendipitous events brings about a change that would not normally occur at that time and place.

Goodyear's discovery of the vulcanization process for rubber is one example in chemistry and the first iron bridge, completed in 1781, is an example from the engineering field. Were it not for a fortunate series of events in Shropshire, England, iron may not have been used for bridge building until the 19<sup>th</sup> century.

In the early 1700's Shropshire, England was a prosperous community with ample raw materials to support a cast iron business run by the Darby family. These raw materials included iron ore, limestone, and coal. During that time period, iron businesses had to be located near the source of the raw materials. Transportation systems and vehicles were unable to move the necessary ingredients for iron to far away sites without extreme effort and expense in the 1700's.

The region around Shropshire was separated by the Severn River. The river was very beneficial to the economy because it provided a

passageway for trade and people. The fact that the river cut deeply through the country side did make it difficult to move people and goods from one side to the other. The region needed a bridge that could span the river without slowing the movement of water traffic. The span across the river was too wide for most bridge styles unless piers were placed in the water to support the deck. The only bridge style that could span the river and support the load of heavy wagon traffic was an arch bridge.

As the community searched for someone to build the bridge, a local cast iron manufacturer took on the project. Andrew Darby III was the third generation of iron makers in the Darby family. Since the raw materials to produce iron in large quantities were nearby and his family owned the iron works, it was natural that Darby chose to build the main span of his arch bridge from iron. Many of the local people doubted Darby's abilities and were concerned that the project was too large and daring to be completed with iron. Darby was determined and eventually ended up investing a great deal of his family's fortune in the project when cost overruns threatened construction.

It is often said that Darby's ovens and furnaces





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may have fired the industrial revolution in England. The Darby family had revolutionized the production of iron by using a material called coke to provide the heat for the iron making process. Previous iron makers used charcoal to provide the heat for iron making. Unfortunately, that meant trees for miles around had to be chopped down to provide the wood to make charcoal. The Darby's baked coal in large ovens to remove its impurities. The material that was left over was coke that burned at very high temperatures in a blast furnace. Trees were saved, miners were put to work mining the coal and limestone for iron production, and the Darby's iron making blast furnaces grew larger and larger.

The iron sections of the bridge were made by pouring liquid iron into huge molds. When the metal hardened and cooled, the molds were broken away and the iron construction pieces were revealed. There were nearly 800 pieces of iron cast in this manner for the bridge. Interestingly, pieces of iron this large had never

been fastened together before so Darby's workers had to design a way to attach the pieces. They ended up using the same techniques to attach the iron pieces that carpenters of that time used to attach large wooden beams and supports. Today we might use rivets for that same purpose.

Darby's bridge included two large stone abutments on the banks on each side of the river. Iron arches extended between these abutments and supported the bridge decking that formed the approaches to the main span of the bridge. The main span presented a larger challenge. Five large arches were cast as two pieces each. The pieces that made up each of these five arches were joined in the center of the bridge above the river. The bridge spanned the river and the road deck was 60 feet above the water so river traffic could move easily under the bridge. A series of serendipitous events had enabled a construction and engineering marvel to become a reality; perhaps before its time.





## HISTORY OF THE TOWERS

Towers and tall buildings have been built for thousands of years. Some were built as part of special events (world expositions), some for military purposes to help a city or castle to see approaching invaders, and some were built to house hundreds of businesses in large cities. Whatever the reason, one thing has remained constant throughout history. There has been an effort to construct many new towers and buildings to be the tallest in the world. Each country that plans a tall tower considers whether the new structure will be designed to be the tallest in the world.

Today, towers are generally constructed for economic reasons but the desire to have the tallest structure still remains. Throughout the last few centuries, the Eiffel Tower, CN Tower and others have laid claim to the status of world's tallest tower or building. Currently, as of 2008, the Burj Dubai has the honor of being the tallest. When the building is completed in 2009 it will surpass the record height it reached when it took on world leadership just a few years earlier.

The challenge to build taller and taller towers raises an important question. Does the desire for taller towers drive the development of new engineering technologies and building materials or do new engineering technologies and building materials drive the development of taller towers? Depending on the tower in question and the time period in history, the answer to the question is probably a combination of both. In many instances the discovery of new building materials like concrete or steel led designers to plan higher and higher towers. On the other hand, projects like the construction of the Burj Dubai have called upon the skills and expertise of engineers and materials scientists to design lighter, stronger materials and new engineering technologies.

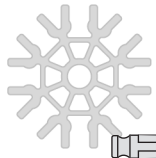
### THE EIFFEL TOWER:

The Eiffel Tower in Paris, France is one of the most recognizable towers in the world. It was constructed in 1889 for the International Exhibition of Paris to commemorate the 100<sup>th</sup> anniversary of the French Revolution.



Additionally, the tower gained fame as one of the first towers in the world to be outfitted with elevators. This added greatly to the accessibility of the structure. People who were unable to tackle hundreds if not thousands of stairs could still see wonderful views from heights the elevators reached. The Eiffel Tower was never intended to be a permanent structure and it was destined to be scrap iron on several occasions. The addition of a tall radio tower for long-distance radio transmission and the role the tower played in communication efforts during the Second World War saved the tower from demolition.

The tower was designed by Gustave Eiffel, a bridge engineer, who was a meticulous planner and precise organizer. His attention to detail and the clarity of his vision and plans made the construction move very smoothly. The contractors completed the tower in less than two years and they were able to keep costs below budget. That alone is a major feat in the construction industry. Eiffel was the one that was ultimately responsible for the success of the project. He was experienced with large



building projects, he knew how to design safe, strong, iron structures, and he paid attention to details. Detail is extremely important when you are asking iron works to produce over 1800 pieces of wrought iron and then asking contractors to put them together in the correct order with about 2,500,000 rivets.

The tower itself is 986 feet tall and if you include the antenna at the top you can increase that height to 1,063 feet. Two environmental factors commonly impact tall, metal towers. They are temperature and the wind. The open, lattice structure of the tower allows the wind to pass right through the tower and design elements included by Eiffel enable to iron to remain strong even when some sections expand up to six inches in the bright sunlight. As other towers moved past the Eiffel tower in height, they had to find other ways to address these environmental problems to ensure their safety and long service.

### THE SEATTLE SPACE NEEDLE:

The Seattle Space Needle was constructed in 1962 as the centerpiece of the World's Fair. At the time, it was the tallest structure in the United States west of the Mississippi River. The tower is 605 feet high and includes a communication antenna at the top. The geology and weather conditions in Seattle are much different than those in Paris and these differences affected the design and construction of the tower.

The northwestern section of the United States is geologically active and the region is also prone to severe weather. With these issues in mind, engineers designed the tower to:

- withstand earthquakes up to a magnitude of 9.5 on the Richter Scale
- withstand winds up to a speed of 200 mph
- be protected from lightning strikes by 25 lightning rods

All of these engineering challenges were successfully addressed to ensure that the tower could be of lasting service to the city of Seattle and its citizens.

Some feel that the Seattle Space Needle is over engineered (built to withstand forces that are beyond what would ever happen) while



others feel much more secure knowing that safety was of paramount importance as the structure was built. There are five main components to the structure. Four steel legs that extend from the base of the observation deck and restaurant near the top of the structure and sweep out from the structure at its base for added support. The center of the tower is a steel column that houses the elevator shafts and stairs. The legs and central column support observation decks and a rotating restaurant that provide visitors and diners a breathtaking view of the city. For added strength and stability, 74 bolts extend 30 feet into the foundation of the tower to securely hold the steelwork in place.

### THE CN TOWER:

In 1968 Canadian National (CN) proposed a communications tower to serve the region around Toronto, Canada. Changes in the Toronto skyline were interfering with communication and microwave transmissions were being blocked. A tall tower to support microwave receptors and communications



antennas was a need that had to be addressed. Construction finally began in 1973 and by 1975 the tower had become the tallest man-made structure on earth at 1,815 feet. The design of this concrete and steel marvel was so impressive that the tower received many engineering awards. It was declared one of the modern Seven Wonders of the World by the American Society of Civil Engineers.

The CN tower is a three-legged structure that includes a central core that is hexagonal in shape. The tower has a very large 'Y' shaped footprint at ground level. In order to support a large structure with a height of over 1,800 feet, a massive foundation of reinforced concrete was required. The foundation extends 50 feet into the ground and is made up of over 9,000 cubic yards of concrete and many miles of reinforcing steel. By comparison, the foundation is almost twice the size of the foundation that supports the Seattle Space Needle.



Two engineering and construction innovations were pioneered during the construction of the CN Tower. First, was a creative way to move the forms that kept the concrete in place as it cured. The technique used hydraulic pressure to raise the forms as concrete below cured and new concrete was being poured. This technique was called a hydraulically raised slip form system (hydraulic pressure raised the forms which slipped over previous work to make space for new concrete to be poured). The second innovation utilized technology from the United States aircraft industry. The Sikorsky S-64 Sky crane helicopter had just come into production and it would enable CN Tower engineers to save considerable construction time and money. The original plan was to use a crane at the top of the tower to lift the 35 sections of the antenna for the tower into place. Using the Sky crane, the crane at the top of the tower was quickly brought down in pieces and the 35 pieces of the antenna were lifted into position. These were both technologies that have influenced the building of other structures around the world.

**BIG BEN:**

The clock tower, now know as Big Ben, houses the largest four-faced, chiming clock in the world. Big Ben is located at the northeastern end of the Palace of Westminster which is often referred to as the Houses of Parliament in Westminster, England. There are other towers that also rise above the palace and one is taller than Big Ben but none are more famous.

The tower is 316 feet tall and features two distinct architectural sections. The first 200 feet of the structure is built in the form of a brick inner tower that is clad with a façade of beautiful limestone. The remaining height of the tower is a cast iron spire. The palace had burned at least once during its history and the addition of a tower with very little wood structural materials served to make the structure better able to withstand fires.

The concrete foundation for the tower has an area that is almost 2,500 square feet and it is approximately 10 feet thick. Although the foundation is small compared to towers of today, Big Ben has stood since 1858. Currently, soil conditions below the tower have caused it to



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lean slightly but efforts are underway to secure its future. By making comparisons between towers produced today with historical towers of the past we are able to see how advances in engineering materials and techniques have enabled us to move higher and higher.

The faces of the clock are 23 feet in diameter

and they are made up of hundreds of pieces of glass mounted in iron frames. Forming a circle with your classmates that is 23 feet in diameter in the gymnasium or parking lot will give you a sense of the size of the clock faces. The clock works behind the faces is powered by a pendulum mechanism and the clock is known for its accuracy.





## THE HISTORY OF WINDMILLS

The windmill has served man as a power source for thousands of years and recent energy concerns have heightened interest in windmill technology. Windmills date back to ancient Persia in the 9<sup>th</sup> century BCE. Technology had not yet been developed to change the direction of the motion provided by turning windmills so they looked much different than windmills of today. Rectangular blades were mounted horizontally and they turned a shaft that was in a vertical position. Essentially the windmills looked something like a ceiling fan sticking up from the floor. The turning shaft could be used to provide power. Windmill designs we are more familiar with did not appear until the 12<sup>th</sup> century CE.

Windmills are used to convert energy from the wind into usable motion that can provide the power to operate machines or produce

electricity. Today windmills are being used as an alternative energy source to lessen demands on nonrenewable resources like oil. Windmills can be fixed or movable structures. A fixed windmill stands in place facing the wind. A movable windmill can be turned on its base to face the wind. Early windmills were turned by animal power while today's windmills use motors to turn them to face the wind. Fixed windmills were common in areas where the prevailing winds were very predictable and dependable. Movable windmills have much greater flexibility and they can be placed in areas with varied wind patterns.

As engineering technology became more advanced and building materials became more sophisticated windmills grew taller and the length of the blades grew longer and longer. Also, computer simulations and extensive experimentation suggested a variety of changes to the shape of windmill blades. These changes

have made windmill blades extremely efficient as they capture energy from the wind. Over the centuries windmills have provided power to thresh grain, pump water, saw wood, etc. Today windmills are used almost exclusively to generate electrical power and to pump water. Windmills once had to be located in places where there was enough wind to provide power and where the products the power was to produce were needed. Since windmills are now used to generate electricity, they can be located where the best wind conditions exist and electric transmission lines can carry that power to where it is needed.

Modern windmills depend on computer technology to make them as efficient as possible. Data from sensors provide the computer with details on the speed and direction of the wind. The computer can respond by turning the windmill toward the wind and possibly altering the angle of the blades to allow them to operate at peak efficiency. If wind conditions become severe and high winds





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could damage the windmill the computer will respond by shutting down the system to protect the windmill from damage. Windmills in the past needed other engineering strategies to get the most from the wind and to provide protection from high winds. Movable windmills mounted on tracks allowed a mill operator to hitch oxen to the windmill to move it toward the wind. Cloth sails were stretched across the framework of the blades on many of these windmills. When the wind moved slowly, the miller could add more sails to the blades. Conversely, when the wind was dangerously strong, sails could be removed to slow the windmill. In each case, engineering technology of the times provided solutions that used available materials and met the needs of society.







## THE HISTORY OF THE TOWER CRANE

As you travel through any major city in the world you are likely to see several large cranes built alongside tall buildings and extending high above those same buildings. These are tower cranes and their history can be traced back to Greek and Roman times. Some of the early Greek cranes used human and animal power to provide the force to lift large beams and construction stones into place. The Romans improved on the mechanics of cranes and applied the principles of simple machines to make them more useful and efficient. They added multiple pulley systems and often used interchangeable booms on the cranes to fit the needs of different lifting tasks. The addition of simple machine technology enabled the Romans to lift objects with much less force than their Greek predecessors.

Building designs called for taller and taller structures and crane technology had to keep pace with these demands. Taller buildings meant cranes standing on the ground were not always able to lift materials high enough. One adaptation was for cranes to be built on the structures they were serving. If a building was thirty-feet tall and a crane was constructed on

that structure, materials could be lifted to make the building even higher. That same engineering technology eventually led to cranes that were disassembled during construction and continually moved to higher and higher floors as the building was constructed. The availability of lighter stronger materials enabled cranes to support and lift heavier and heavier items during construction. Wood cranes were replaced by iron and eventually, iron cranes were replaced by steel cranes.

The tower crane we see in cities today is the result of centuries of innovation and designs that have evolved over the centuries. A tower crane is constructed next to a new building and it is able to grow as the building grows. In the past, a series of cranes were needed to keep lifting crane sections higher and higher as the building grew. New technology uses hydraulic pressure to lift the top of the crane so new sections can be added below. The crane is able to grow along with the building and the need for costly delays to breakdown the crane and lift it to higher levels is eliminated. As the crane increases in height, it is attached to the building itself to maintain its stability. When a building is complete and the crane is no longer needed, the same hydraulic systems that pushed it ever higher will support the top of the





## Seven Historical Perspectives

crane until sections below can be removed. Just as the crane grew higher and higher with the building, it grows shorter and shorter when its job is complete and it must move to its next construction site.

Advanced applications of simple machine concepts make tower cranes efficient systems for lifting heavy equipment and materials to the top of tall construction projects. Some of the largest tower cranes are able to lift objects that weigh tons at a distance of 100 yards from the tower of the crane. The simple machine concepts most often used in tower cranes are levers and pulleys. The short boom and the long boom on a tower crane are essentially a lever balanced on the top of the tower. The short boom is often outfitted with tons of concrete to counterbalance heavy objects that are lifted by the pulley systems on the longer boom. The crane operator is often able to move the massive counterbalance closer to the tower or further from the tower depending on the weight the system is lifting. Can you describe how the ability to move the large counterbalance weight makes the tower crane better able to do its job? Pulley systems on the large boom include many fixed and movable pulleys that multiply the force acting on the load the crane is lifting. That means a smaller motor is able to lift large loads as less force is required when fixed and movable pulleys are used in combination.



# FIVE ENGINEERING OCCUPATIONS

## THE ARCHITECT

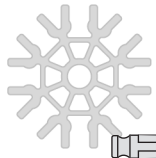
The term architect comes to us from the Latin for chief builder. The concept of chief builder was certainly appropriate in ancient times but as time passed, the role of the chief builder changed. The architect became the individual who planned every detail of structures from homes to large buildings, towers, bridges, etc. Today architects must take a rigorous college program of study in preparation for their career. An architect is considered to be a professional and after years gaining experience working for a large architectural firm, they may seek to become a partner in a prestigious architectural firm or to establish an architectural firm of their own. Which ever path they take in their career, they become part of a team of professionals who work together to ensure that their clients have the perfect plans to build the structure they envision.

Sometimes a family will hire an architect to design a home or an addition to their existing home. The resulting plans for the project are then carried out by a general contractor who brings together all of the tradesmen who will construct the building. Each of the various

trades (electrical, plumbing, framing, etc.) will receive plans called blueprints from the architect outlining exactly the materials they are to use and location for each of the systems they will add to the structure. Throughout the construction process the architect and the general contractor oversee construction and deal with any issues that arise during construction.

Larger architectural firms with large staffs are able to take on larger projects that serve communities, small businesses, etc. These firms prepare bids to design and plan buildings and structures to serve the public or businesses. They may design schools, government buildings, recreation centers, malls, department stores, and more. During the bidding process, the architect is competing with other firms to be chosen as the actual architect for the project. Preliminary drawings are prepared, small, scale models of the structure and its surroundings are constructed and a comprehensive budget is crafted. This information provides the potential client with projected costs for the architectural services and the building itself. The clients review all of the proposals and they choose one firm to proceed with the project. The architects at that





## Five Engineering Occupations

firm prepare final designs and plan all aspects of the construction process. The relationship between the architectural firm and the general contracting firm that is chosen to actually construct the structure will work together very closely throughout the project. Blueprints need to be reviewed, site inspections need to be made, and construction problems need to be addressed in a timely manner to keep the project on schedule. The architectural firm must ensure it has the professional staff on hand to complete the project or they must contract with engineering firms who are able to provide structural engineering support, environmental engineering services, etc.

The largest construction projects for skyscrapers, large bridges, government complexes, huge hotels, etc. require the use of specialized architectural firms who have been successful with these types of projects in the past. Every major city has several such architectural firms who have designed, planned and overseen the construction of the towering buildings and majestic bridges that dot the

skyline. These firms attract the finest architects from around the globe and they provide complete services to the clients they serve. They will likely have a full range of engineering specialties on staff and they have the capacity to design, plan, organize, oversee and complete construction projects of any size.

Whether an architect is drawing up plans for the addition of a bedroom to a house or planning a new skyscraper for a large city, their clients place great trust in their schooling, reputation, and experience. There are extensive resources on the Internet that can provide you with more details about a career as an architect. The financial rewards are significant and there is great personal satisfaction knowing that you are responsible for the design of buildings you see each day in your community. Explore the educational and training requirements for a position in the architectural field. If being an architect does not match your goals, you may wish to investigate related careers that support the work of an architect or architectural firm.





## THE STRUCTURAL ENGINEER

**S**tructural engineers work closely with architects during the design and planning of construction projects. Since architects and contractors have vast experience designing and planning homes and small buildings, they may not need the services of a structural engineer on these projects. If however special building materials are used in the project an architect may call upon their expertise to ensure the structure will serve its purpose. For example, the advent of concrete roofing shingles for homes in warmer climates has required that structural engineers be a part of the home's design. Their input will ensure that the building's structure will be able to support the massive weight of the shingles and transfer that weight safely to the ground. In many respects that is the role of the structural engineer on any project large or small: ensure that the structure can withstand the loads that are placed upon it and transfer those loads safely to the ground or bedrock.

In ancient times the role of structural engineer was not clearly defined but it was a science that was changing and evolving as new innovations came about in building materials and construction techniques. Trial and error often resulted in structural innovations. Early buildings made of stone probably had a flat roof made of wood members covered with soil, rock, or other materials. The weight of the roof was passed to the walls and then to the ground below the structure. With the advent of pitched roofs and the peaked roofs we see today, new strategies to support those roofs needed to be designed and tested. As history progressed domed buildings presented other problems that needed to be addressed. Today, the person who would accept that challenge would be the structural engineer. Domes were picturesque but as they sat on top of a set of walls they caused forces that could not be transferred to the ground easily. The bottom of the dome pushed outward on the walls and failures resulted. In response, some domes were outfitted with massive chains that circled the bottom of the dome and counterbalanced the outward forces against the walls. With the outward forces in check, the weight of the dome was passed safely down the walls to the ground.



Bridge building has seen great advances that have required the input and expertise of structural engineers. As we look at bridge innovations over the centuries we see a progression that includes: beam, arch, truss, trestle, cantilever, suspension, and cable-stayed. As the need for longer and stronger bridges grew, structural engineers were called upon to investigate the structural aspects of new designs or to present designs of their own. Truss bridges are an excellent example. There are many distinct truss bridge styles that were designed by structural engineers across the United States. To this day they carry the names of those engineers or the companies or communities they worked for. With each of the bridge styles mentioned above, the role of the structural engineer today is to ensure that the various loads and forces the bridges will experience are transferred safely to the ground. These loads include: the weight of the bridge, the weight of the expected vehicle traffic, the shock load of high speed vehicles entering the bridge, and environmental loads like wind, ice, etc.



## Five Engineering Occupations

Today structural engineers are called upon to provide structural designs that allow for large open spaces inside buildings. Many sports stadiums and entertainment venues have required structural engineers to use innovative construction techniques and specialized building materials to span great distances. Unfortunately, some of these structures have failed and collapsed. In these circumstances structural engineers take on a new role. They

become inspectors and investigators in an attempt to determine why the structure failed and to make recommendations that will lessen the chance of future failures. Many structural engineers work directly for government agencies or contract with them to inspect buildings, bridges, and other structures both public and private. Their skills and expertise serve to make our lives safer.





## THE MATERIALS SCIENTIST

Rust . . . it ruins our cars, deteriorates steel and iron structures and it is very costly to prevent. Painting is one solution but the iron or steel needs to be repainted on a regular basis. Isn't there any way to prevent corrosion? That sounds like a problem for the materials scientist. The materials scientist is a highly trained specialist with an extensive background, if not a doctorate, in chemistry.

The materials scientist can take on many roles in support of the construction and upkeep of buildings, towers, bridges, etc. They can develop new and exciting materials to revolutionize construction. These innovations might include new metal alloys that are lighter and stronger, new coatings for metals to stop corrosion, or composite building materials that combine the best features of a variety of materials. Other materials scientists may move into the field of forensic engineering and investigate structural failures linked to material failures. They may discover that a bridge fell because of metal fatigue or identify instances where metal coatings were applied incorrectly and corrosion set in to cause a radio tower to collapse. Still other materials scientists specialize in testing materials to determine issues related to their safety. For example, asbestos and materials containing formaldehyde that were once used in construction were determined to be health hazards. Materials scientists helped to uncover these types of safety problems and to recommend that these materials be removed from buildings. Companies that produce building materials maintain a staff of materials scientists to improve the construction materials they manufacture and to develop exciting new products that will be the latest craze in the industry.

Steel and metals companies will be looking to their materials scientists to investigate and experiment with the formation of new alloys. Once a new alloy has been identified it must go through extensive testing to explore its production, application in construction, need for protective coatings, chemical properties and how it reacts with other building materials chemically. The materials scientists at fiberglass companies work with non-metals and the chemistry associated with their materials is completely different than

that of scientists working with metals. In either case, the goal is to develop, refine, and produce construction materials that are stronger than existing materials, lighter in weight than existing materials, or that have sound deadening or features for specialized uses.

Ages in history were often delineated by the materials that were most used during those time periods. The Stone Age, the Bronze Age and the Iron Age were time periods in the history when a single material had a major impact on the entire fabric of society. Each time period showed advancements over the period before and the sophistication of the chemistry involved became more complex. Materials scientists owe much of what they know about chemistry and metallurgy to the work and record keeping of alchemists who lived during the Middle Ages. The alchemists tried relentlessly to find ways to chemically change lead into gold. In the process they investigated almost every known metal and they maintained extensive records of both their successes and failures. Many of those records survived and the information they provided led to the modern science of metallurgy. Also, they never found a way to make gold from other metals.

As you work with the models in the Engineering Marvels: Buildings, Structures and Machines Set you will notice that the structures that came earlier in history are made from simple materials while the more modern structures incorporate more and more complex construction materials. The Internet and resource materials in the library will provide research information that can be used to further investigate the field of materials science and to provide deeper insight into the exciting career of the materials scientist.





## THE ENVIRONMENTAL ENGINEER

For many years environmental issues have taken center stage in politics and our everyday existence. Environmental concerns have long been addressed by the building and construction industry but recent environmental rules, regulations and legislation have opened up the field of environmental engineering. Environmental engineers are a valuable resource to architects and contractors as they work to construct buildings, bridges, and structures that maintain the condition of the local environment. Additionally, environmental engineers provide direction and assistance during construction to ensure that the procedures followed by the general contractor and subcontractors do not harm the surrounding environment.

Historically environmental concerns were generally related to sanitation. As population dynamics changed and more and more people began moving into cities, sanitation became a great concern. Where was fresh water to come from and how was it going to get to the people that needed it? Was there to be a well in the center of town for everyone to use? What will happen to personal waste, garbage and trash?

Will the city have a public sewer system? These were all questions that would be answered by the environmental engineer today. Ancient Romans were very concerned with both personal and community health. They constructed public restrooms in their cities and had sewer systems to direct waste outside the city. Additionally, cities like Rome did not have sufficient water to support its population. Extensive systems of large, stone aqueducts allowed water to flow to Rome and other Roman cities from mountains that were far away. Many sections of these aqueducts survive today. The Roman experts that planned, designed, and constructed these elaborate systems to bring fresh water to cities and to remove waste did not carry the title of environmental engineer but that is what we would call them today.

Environmental engineers in the construction industry work closely with architects and contractors to ensure that the structures they are building have a minimal impact on the surrounding environment. In many instances, local regulations will require that an environmental impact study be complete before a project is approved. Some architectural firms will have environmental







engineers on staff while others will hire environmental engineering consultants to work for short periods of time on individual projects. Some of the specialized environmental engineers that may assist architects have expertise in environmental law, pollution prevention, recycling, toxic waste clean-up and more. Some of these specialties will be called upon when construction is being designed and planned while others will address issues related to the actual construction process.

Throughout construction of a structure there are environmental concerns related to the actual construction site. Each of these issues is remedied by input from environmental engineers. Some contractors have received specialized instruction from environmental engineering firms to ensure that they employ environmentally sensitive procedures at their construction sites. Other firms will seek input prior to each new construction project they undertake. Some common environmental issues that need attention at the construction site are: soil erosion must be avoided so runoff

does not foul local roadways and water supplies, trash removal, recycling of personal trash generated by workers, hazardous material handling and disposal, and the collection, sorting, and sale of recyclable construction materials. The environmental engineer's attention to detail helps to make the contractors good stewards of the environment. They also ensure that the project has done everything it can to lessen to overall impact of the project on the environment.

You can research environmental engineering specialties and careers on the Internet. Gather information that will help you to better understand the role of the environmental engineer in today's businesses and communities. The systems and technologies they design positively impact our lives each and every day. Is this a profession that would be of interest to you? This would be an excellent career choice if your goal is to serve both your community and your fellow man to the best of your ability.



## THE CITY/SITE PLANNER

The city planner is hired by a city, town or community government to make recommendations as to the best use of land in the community to ensure organized growth and prosperity. A city planner's duty is to assist governing bodies as they make decisions that reflect their vision for the community. They will deal with issues related to renewal projects, landscape development, major construction projects, convention centers, zoning concerns, recreational sites, transportation systems and more. A well planned city provides a safe environment for residents, accessible business districts, parks, open spaces, an organized transportation system, public transportation, and related entities and services. If a city planner has worked on the design and development of a large construction project in the community they may turn that task over to a site planner who will follow the project through to completion. The coordinated efforts of the city planner and the site planner ensure that communities have the information they need to make informed decisions. They also see that the decisions of the city government are carried out to benefit the community and its residents.

Throughout history the role of the city planners has changed. When cities were small and based on agriculture and trade the use of land and community resources was directed toward transportation and storage facilities. Throughout history defense was also a major concern for cities. Castles, forts, and a variety of other defensive systems had to be designed, planned, and constructed to protect the population. City planners did not exist in these early cities but people in government or people of influence carried out many of the duties of modern city planners. Modern city planners have very defined roles and duties that enable them to assist politicians as they make decisions. The city planners must then work to ensure that construction projects and other initiatives are carried out as approved by city officials. Unlike the other career opportunities presented in the Engineering Marvels Set, the city planner and site planner are employees of the community and not working on behalf of developers, construction firms, or architects. Their goals and responsibilities are thus



different from those of people in commercial careers.

Today's city planners are concerned with planning that leads toward sustainable development and a healthy population. To that end the city planner will work to reduce automobile traffic, take part in planning public transportation needs, recommend strategies to reduce pollution, address environmental issues and plan for economic growth that evolves along with the community. Social and political issues impact decisions that government officials make based on the input of city planners. A strong working relationship between the city planner and the decision makers in a community will provide an opportunity for a healthy exchange of ideas and plans to make the city a great place to live.



There are many theories that have influenced city planning in the last century. During the 1960's many city governments sought to provide public housing in high rise apartment buildings. This strategy was very efficient but it soon became evident to many city governments that crime and social problems surface when people are housed too closely together. Most of these high rise buildings have come down and the density of people in public housing has been significantly decreased. Today many cities offer single family or duplex structures to support public housing needs. Another common theory that influences city planning revolves around the issue of neighborhood decay. The theory essentially

states that neighborhood decay is infectious and will lead to further decay. As a result, city planners work very hard to reverse neighborhood blight and assist neighborhoods as they attempt to instill a sense of neighborhood pride.

How are planning decisions made in your community? Does your town or city have a city planner or a planning commission that assumes the role of the city planner? As you gain a better understanding of your community, its organization, and its plans for the future you may realize that city planning is a career option that may be perfect for you.