West Point

Engineering Design Contest

THE WORD IS ON THE STREET AND IN CHAT ROOMS AROUND THE WORLD, IN ORDER TO CELEBRATE IT'S 200TH ANNIVERSARY, THE UNITED STATES MILITARY ACADEMY (USMA) IS CONDUCTING A FREE, INTERNET-BASED, ENGINEERING DESIGN CONTEST FOR STUDENTS IN KINDERGARTEN THROUGH TWELFTH GRADE.

by
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The West Point Bicentennial Engineering Design Contest honors West Point's 200 years of service developing leaders of character for the nation and underscores the fact that the USMA also has the distinction of being the first institution in the United States to offer a formal program of instruction in engineering. The contest is endorsed by and sponsored in part by the American Society of Civil Engineers who coincidentally are marking their 150th anniversary. Participants will use a unique, award winning, computer-aided design software package called the West Point Bridge Designer. The concept for the contest is unique because students will register, enter, have their entries judged, and receive performance feedback entirely via the Internet. The software can be downloaded free of charge from the contest Web site at www.usma.edu/bridgecontest. If this is the first you've heard about the contest, don't worry, you still have time to get your students ready to participate—it starts November 11, 2001. Even if you don't enter the contest, you can still use the software to explore engineering design. Students do not need any special knowledge of math or science to use the West Point Bridge Designer.

HOW THE CONTEST GOT STARTED

The United States Military Academy at West Point, New York was established by Congress in 1802. The Academy was intended not only to educate officers for the U. S. Army, but also to address the young nation's critical need for engineers, both military and civilian. West Point is generally recognized as the first school of engineering in the United States and its 19th Century graduates made a substantial contribution to the development of the nation's infrastructure. According to author Lawrence Grayson, "Of the engineering graduates engaged in public works before 1840, a sizable fraction were West Point graduates, and at least 30 percent of them served as chief engineers of important projects on railways, canals, docks, wharves, roads, and other non-military activities."

The idea for the design contest originated with the Bicentennial Steering Group, a strategic planning committee charged with organizing the entire West Point Bicentennial. Given the civil engineering focus of the early USMA curriculum, the committee decided that a balsa bridge-building competition would be an appropriate format for the contest.

CONTEST GOALS

The principal goal of the West Point Bicentennial Engineering Design Contest is to celebrate the Academy's 200 years of service to the nation by (1)calling attention to the institution's engineering heritage and (2) providing contestants with a high-quality educational experience. Consistent with these goals, the following specific objectives for the contest have been developed:

- Achieve the broadest possible participation from U.S. high-school and middle-school students.
- Provide a unique, engaging educational experience that stimulates interest in math, science, and engineering.
- Provide a mechanism for teachers to integrate the contest into classroom instruction in math, science, and technology.
- Provide a mechanism for engineering practitioners to integrate the contest into outreach activities.
- Provide the contest at no cost to participants.
- Fund the contest largely with private donations.
- Administer the contest without placing excessive time demands on the USMA faculty or staff.

A CHANGE IN DESIGN TO MEET THE GOALS

Soon after receiving the mission to develop an engineering design contest, the senior leaders of the Department of Civil and Mechanical Engineering determined that the Bicentennial Steering Group's proposed balsa bridge-building concept was incompatible with the goals and objectives of the contest. If done at no cost to participants, such a contest would be prohibitively expensive. It would require an extensive network of local and regional hosts and judges. Such a competition would hardly be unique. There are already numerous well-established, high-quality, regional and national competitions requiring the design and construction of model structures and mechanical devices. Odyssey of the Mind, the FIRST Robotics Competition, and the International Bridge Building Competition are three notable examples. Furthermore, by their very nature, these sorts of competitions tend to be exclusionary, either because of costs or by limiting the number of participants. Such restrictions and costs, though entirely appropriate, are likely to result in only a small, select group of students participating from any given school. We sought to create a competition that would be accessible to a substantially broader population of students, particularly to students who might not otherwise be interested in an engineering competition.

Finally, in our own experience, model bridge-building projects are often poor representations of the engineering design process, particularly when they are done at the

Images: **Creative Graphics**, Goshen, NY middle-school or high-school level. Balsa bridges are typically not designed at all. The student simply builds a bridge based on a photograph or a vague idea of what a bridge should look like. To the extent that there is a design process, it is generally not informed by math or science, and it is seldom iterative. In such projects, model bridges are loaded until they fail, but there is often no opportunity for the student to understand why the failure occurred or how the design might be improved. Students who participate in these projects may develop significant misconceptions about the nature of engineering design.

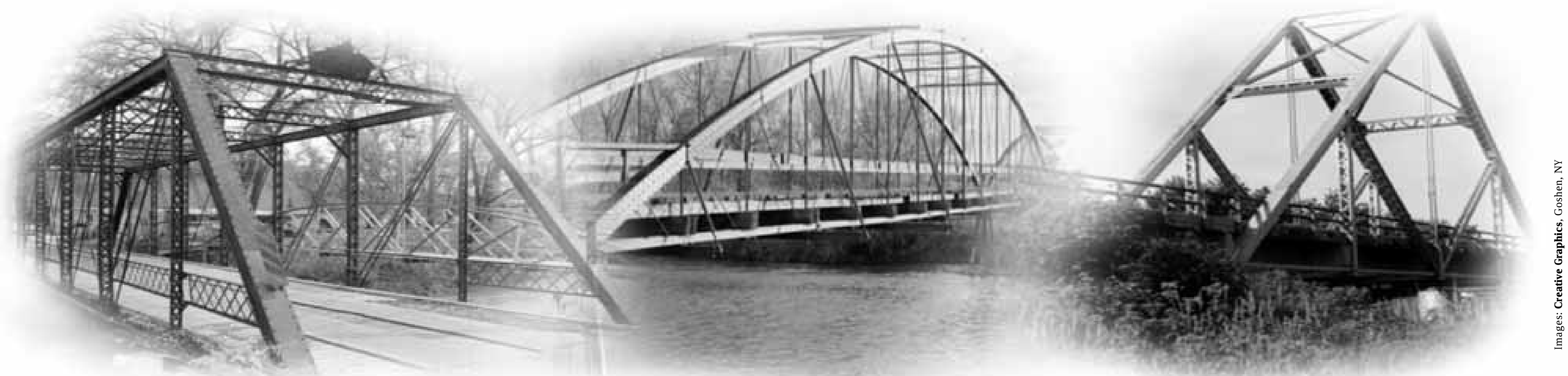
Recognizing these inherent problems with the balsa bridge-building format, we proposed and received approval for an entirely different approach that uses computer simulation and the Internet to: (1) greatly expand the accessibility of the contest, (2) reduce its cost, in both dollars and faculty time, (3) enhance the realism of the design experience, and (4) give the contest a unique, high-tech flavor. The new plan follows this sequence:

- The contestant accesses a website to register for the contest and read the rules.
- The contestant downloads a copy of the West Point Bridge Designer—a specially developed software package that can be installed locally on the contestant's personal computer.
- The contestant uses the West Point Bridge Designer to design, load-test, and optimize a highway bridge, consistent with a built-in set of design specifications. The basis for optimization is minimum cost.
- The contestant saves the design and uploads it to the contest website for judging.
- The website automatically evaluates the design by calculating its cost and validating its load-carrying capacity. If the design passes the load test, it is saved to the contest database, and the current standing of the entry is computed. The contestant's score is the cost of the design. The lower the score, the higher the standing.
- The website generates a new web page providing feedback on the contestant's current standing; e.g., "You are currently ranked 375 of 10,467 entries." If the entry is in the current top 40, it is automatically posted to the contest scoreboard—another dynamically generated web page.
- Based on this feedback, the contestant may modify the design or create a new one, then submit the new entry. There is no limit to the number of entries a contestant may submit.

Implementation of this ambitious concept required extensive software and website development; careful formulation of the contest rules, eligibility criteria, and schedule; and aggressive fund-raising.

OUR HISTORY

Development of the West Point Bridge Designer began in 1995 and has continued to the present. Recognizing that this software is crucial to the successful implementation of the Bicentennial Contest, we elected to put the Bridge Designer into the hands of as many students and teachers as possible in order to solicit their feedback on how to improve it. We made the software available for free download from the worldwide web, starting in 1997. Currently about 200 copies are downloaded each day.



Images: **Creative Graphics**, Goshen, NY

Shortly after we placed the West Point Bridge Designer on our website, we began receiving a steady stream of e-mail requests from users seeking feedback on the quality of their designs; e.g., "My design costs $2417; how am I doing?" Largely to prevent e-mail overload, we established a Best Scores web page, which lists the lowest costs of bridge designs created with the software. Users can now refer to this web page to assess their performance. Anyone who creates a design with a cost that is lower than one of the current best scores can have his or her name posted by e-mailing a copy of the design to the webmaster. To date, over 100 users from all over the world have done so. Though we never intended to do so, the Best Scores page created a de facto international design contest, albeit an informal one with no prizes, no rules, and no end date. Unlike the automated website we will be using for the West Point Bicentennial Engineering Design Contest, the current Best Scores page is manually maintained and updated. Nonetheless, it has done much to validate the concept of an Internet-based design contest.

Since 1997 we have also received over 600 e-mail messages and letters providing feedback on the West Point Bridge Designer, including many insightful suggestions for improvement. We used this feedback to improve the functionality and educational effectiveness of the software. The most recent release of the Bridge Designer (Version 4) also incorporates a newly designed user-interface, consistent with Alan Cooper's goal-directed principles for user-interface design.

THE WEST POINT BRIDGE DESIGNER

The West Point Bridge Designer software package was developed to provide students with a realistic, hands-on introduction to engineering through the design of a steel truss bridge. Using this software, the students can:

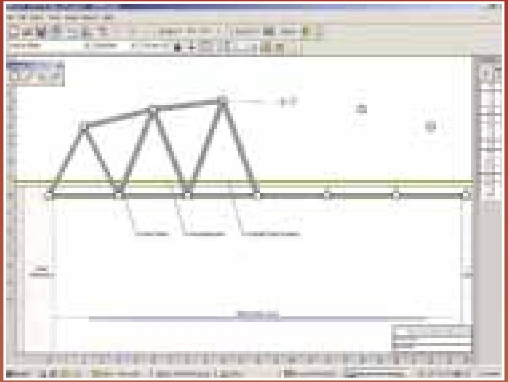
- create a structural model graphically by drawing joints and members on the computer screen with the mouse;
- define the member properties—size, shape, and material—by selecting from drop-down lists;
- run a simulated load-test of the structure to determine if it is strong enough to safely carry a standard truck loading, in combination with its own dead weight;
- display a 3-D animation of the load-test with members color-coded to indicate tension (blue), compression (red), and internal force-to-strength ratios (indicated by the intensity of color);
- graphically modify the design to strengthen any inadequately designed members; and
- minimize the cost of the design, by adjusting member properties or modifying the geometry of the structure.

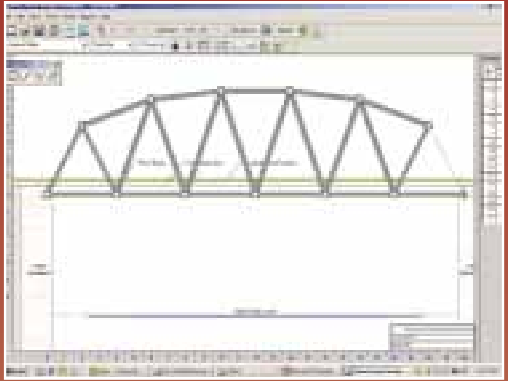
The most recent release of the West Point Bridge Designer is written in Microsoft Visual Basic 5.0 and requires an IBM-compatible computer running Windows 95 or better. A detailed description of the software and the instructional strategy on which it is based can be found in the Internet database of the National Engineering Education Delivery System (NEEDS) http://www.needs.org.

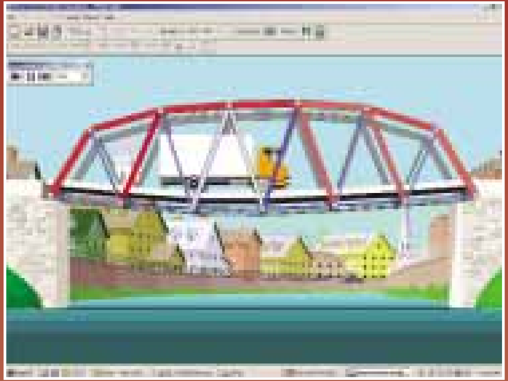
ELIGIBILITY AND RULES

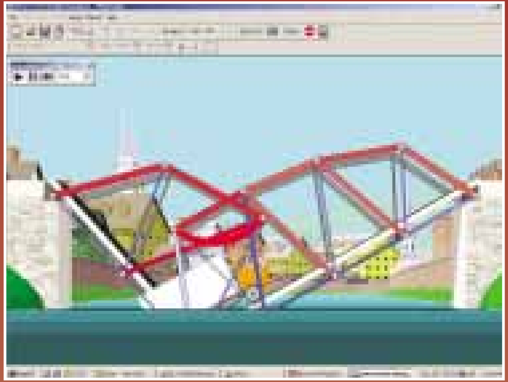
Once we developed the West Point Bridge Designer and could demonstrate the viability of an Internet-based contest, we were able to develop a consistent set of contest rules. To a large extent, this process consisted of posing and answering a series of fundamental questions:

- **Who should be eligible to compete?** Though the focus of the contest is on middle school and high school students, we saw no compelling reason to prevent younger students from participating. Thus we decided that the contest would be open to all K-12 students in U.S. schools and to all U.S. citizens attending K-12 schools outside of the U.S. For the sake of simplicity, we chose not to establish separate age categories. Given that the West Point Bridge Designer emphasizes critical thinking and problem-solving skills—not content knowledge—we believe that middle-school students will be able to compete with high-school students on reasonably equal terms. Our qualitative experience with submissions to the "Best Scores" web page supports this assertion.
- **Should students compete individually or in teams?** In deciding this issue, we recognized the educational benefits of having students work in teams but did not want to exclude the individual student who might be unable to find a teammate. Ultimately, we decided to allow students to compete individually or in teams of two. However, we established a system for awarding prizes that will indirectly encourage students to enter in teams.
- **How will we know if a design submission is really the product of the student team that submitted the entry?** In deciding on this issue, we noted that preventing a student from collaborating with anyone but his or her teammate would be both impractical and undesirable. To enhance the educational benefit of the contest, we seek to promote, not prevent the collaborative involvement of teachers and engineering practitioners with the student teams. Nonetheless, we certainly do not want to award prizes to students who contributed little or nothing to their design submissions. Thus we decided that the contest will be conducted in three rounds; a Qualifying Round (November 11, 2001-February 28, 2002), a Semi-Final Round (March 16, 2002), and a Final Round (April 27, 2002). During the three-month Qualifying Round, there will be no restrictions whatsoever on collaboration. Student teams may receive assistance from anyone as they develop and submit their designs. During the Semi-Final and Final Rounds, however, students will not be allowed to collaborate with anyone but their own teammates. In these two rounds, teams will have only three hours to develop their bridge designs based on a new set of design specifications. Only the top 40 teams from the Qualifying Round will participate in the Semi-Final Round. Each of these teams will be monitored by a teacher or contest volunteer, who will enforce the restriction on collaboration. The top six teams from the Semi-Final Round will compete in the Final Round, which will be conducted in a computer lab at West Point. Again, contest monitors will ensure that the restriction on collaboration is strictly enforced. Through this three-round process we hope to promote collaborative learning in the early phase of the contest, while ensuring individual accountability for performance in the final phase, the one for which prizes will be awarded.









The user creates a structural model of a truss bridge by drawing joints and members on the screen. The load-test simulates a standard truck crossing the newly designed bridge.

Images: **Steve Ressler**

- **How will we know that an entrant is really eligible to compete?** Verification of eligibility is certainly one of the greatest challenges in an Internet-based competition. We addressed the issue in two ways. First, contestants must certify their eligibility during the web-based registration process. Second, in the final week of the Qualifying Round, the Contest Coordinator will call the schools of the current top 40 teams to verify their eligibility with a school administrator. Any registered entrant whose eligibility status is not confirmed by his or her school will be disqualified. Thus we will be assured that only eligible teams advance to the Semi-Final Round.
- **What if identical designs are submitted by two different teams?** We addressed this issue with a simple and easily enforceable rule: if a design submission is identical to any previous entry, the later submission is rejected. The rule is analogous to a patent. Credit for a new idea goes to the person who registered that idea first. The rule is convenient, not only because it eliminates the need for a "tie-breaker," but also because it can readily be enforced automatically by incorporating a check for identical designs into the function of the contest website.
- **Will the contest scoreboard reduce participation in the contest?** If the top 40 scores are posted and continuously updated on the Scoreboard web page, it is likely that the level of participation in the Qualifying Round will suffer. Students are unlikely to submit a design if they already know it will not qualify them for the semi-finals. And as the three-month Qualifying Round progresses, the best scores will continue to improve. Thus, if these scores are posted, the number of design submissions is likely to get progressively smaller. We have addressed this issue by designing the contest web site so that only team names, schools, and submission dates will be posted on the Scoreboard for the top 40 designs. The actual numerical scores will remain secret until the Qualifying Round is over.
- **Are there prizes?** The grand prize is $15,000 cash scholarships for each first place team member. The second place team members each receive $10,000 cash scholarships and the third place team members will receive $5,000 cash scholarships. Additionally, the top six teams competing in the finals at West Point will all receive notebook computers. These students will also have the opportunity to see West Point first hand and learn about the outstanding educational opportunity offered by the United States Military Academy.

The complete contest rules are provided on the West Point Bicentennial Engineering Design Contest website at: http://bridgecontest.usma.edu/rules.htm.

In the three years since the West Point Bridge Designer was first made available on the Internet, the software has become well-established as a valuable educational tool. We know of hundreds of schools currently using it in their math, science and technology curricula, and the feedback from middle-school and high-school teachers has been overwhelmingly positive. The Educational Activities Department of ASCE formally endorsed the Bridge Designer as an educational tool. Also, the software was recently named as one of two winners of the 2000 Premier Award for Excellence in Engineering Education Courseware. (See http://www.needs.org.).

We owe a special thanks to the American Society of Civil Engineers and the Department of the Army for providing the majority of the funding for this project.

GET STARTED!
Log onto
www.usma.edu/bridgecontest
It's time to explore engineering design.

Col. Stephen Ressler is Professor and Deputy Head of the Department of Civil and Mechanical Engineering at the U. S. Military Academy. He created the Bridge Designer program.

Col. Eugene Ressler Steve's brother and Professor and Deputy Head of the Department of Electrical Engineering and Computer Science at the U.S. Military Academy. He designed the back-end programs that deliver the Bridge Designer and score and keep track of the contest.

Maj. Steven Schweitzer is an Army aviator and an Instructor in the Department of Civil and Mechanical Engineering at the U. S. Military Academy. He designed the user-interface for the program.

Cathy Bale is the Public Relations coordinator for the project.

You Can Build It

One of the clear disadvantages of our concept for the West Point Bicentennial Engineering Design Contest is that contestants do not build a physical product as part of the design process. Feedback from middle school and high school teachers suggests that there is strong demand for a hands-on component of the project. Specifically, many teachers have asked for a methodology that would allow students to design a bridge using the West Point Bridge Designer, then build a physical model of the same structure and load-test it to validate the design. We recognize that this sort of hands-on project is desirable from an educational perspective, but it clearly would not be practical in the context of our Internet-based contest. We have addressed this issue by developing a series of five lesson plans that tie the Bridge Designer software to a hands-on bridge-building project using manila file folders as the construction material. The lesson plans are now available for download at http://bridgecontest.usma.edu/resources.htm. The learning activities provided in the manual are:

Photo: **Creative Graphics**

(1) Build a Model of a Truss Bridge
(2) Test the Strength of Structural Members
(3) Analyze and Evaluate a Truss
(4) Design a Truss Bridge using the West Point Bridge Designer
(5) Design and Build a Model Truss Bridge

These learning activities are not part of the contest, but they will provide a mechanism for teachers to integrate the contest into classroom instruction in a meaningful way.

Why Cardboard?

At first glance, cardboard from manila file folders might seem an odd material to use for bridge-building projects. But, in fact, I have found it to be far superior to the more traditional model bridge-building materials—balsa wood, popsicle sticks, toothpicks, and pasta.

Here´s why:

File folders are readily available and very inexpensive.

Cardboard is easy to work with. It can be folded, cut with scissors, and glued using common household adhesives.

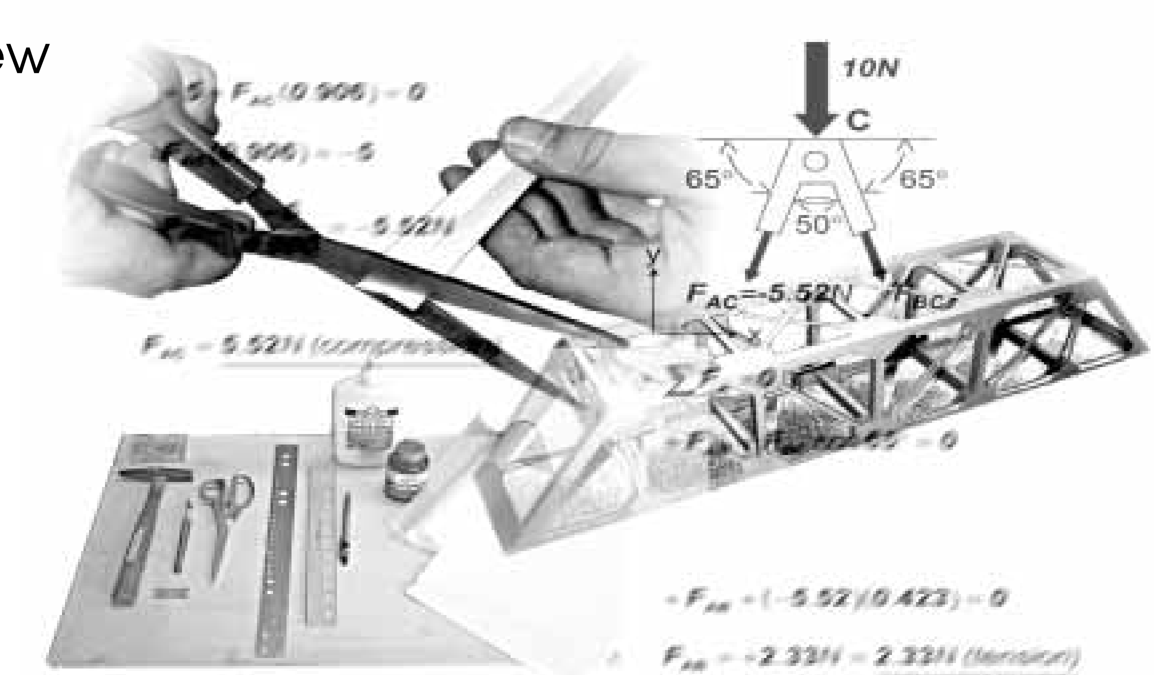
The behavior of cardboard as a structural material is surprisingly predictable.

Cardboard provides the capability to build two fundamentally different kinds of structural members, hollow tubes and solid bars. Understanding how these two types of members work is an important part of understanding structural engineering.

Cardboard provides the capability to build connections that are stronger than the members they join. I can't overstate the importance of this characteristic. Throughout the Learning Activities Manual, you will learn how to design structural members that are strong enough to carry load safely. But a well-designed member is of little use if its connections fail before the member itself does. A chain is only as strong as its weakest link. If you've ever built and tested a truss bridge made of balsa wood or popsicle sticks, you know that these structures almost always fail at the connections. As a result, their load-carrying capacity is less than it could be and, more importantly, is almost impossible to predict analytically.

So download the Learning Activities Manual. Head for the supply closet, grab an armload of file folders, and let's build some bridges!

Overview



Images: **Creative Graphics**

The five learning activities are as follows:

Learning Activity #1: Build a model of a truss bridge. In this activity we will build a model bridge from cardboard file folders. The bridge has already been designed, and accurate drawings and fabrication instructions are provided. Through this activity, students will learn bridge terminology construction techniques, and some basic concepts in physics and structural engineering. Students do not need any special knowledge of math or science to do this activity.

Learning Activity #2: Test the strength of structural members. In this activity we will use experimental testing to determine the strength of structural members made of file folder cardboard—the same stuff we used to build our bridge model in Learning Activity #1. The data obtained from these tests will be used extensively in Learning Activities #3 and #5. Students will learn some basic concepts from engineering mechanics, as well as procedures for designing and conducting experiments. To do this activity students need only basic arithmetic skills and the ability to create a graph. The ability to use a spreadsheet program is helpful but not required. This activity requires the use of a simple wooden testing device; Instructions for building the device are included in Appendix C.

Learning Activity #3: Analyze and evaluate a truss. Here we will calculate the internal member forces in our model truss bridge. We will then evaluate the structural safety of the truss by comparing these calculated forces to the member strengths we determined experimentally in Learning Activity #2. Through this activity, students will learn more advanced concepts from physics and engineering mechanics. Students need to apply geometry, algebra, and trigonometry to do the activity successfully. A review of key concepts from trigonometry is included; however, students who have not yet learned geometry or algebra will not be able to do this project.

Learning Activity #4: Design a truss bridge with a computer. In this activity we will design a full-scale highway truss bridge using the West Point Bridge Designer software. The design process includes working through multiple iterations to ensure that the structure will carry the prescribed loads safely and at minimum cost. Through this activity students will learn the engineering design process and will have an opportunity to reinforce many of the basic structural engineering concepts learned in earlier activities. This activity also includes an overview of how actual bridges are designed and built. Students do not need any special knowledge of math or science to use the West Point Bridge Designer.

Learning Activity #5: Design and build a model truss bridge. Here we will apply what we have learned in the previous four activities to design, build, and test a model truss bridge. Students should have completed Learning Activities #1, #2, and #3 to do this project successfully; however, if they do not have adequate math background to complete Learning Activity #3, they can bypass the mathematical structural analysis by using the Gallery of Structural Analysis Results provided in Appendix B. The gallery presents a complete set of computed analysis results for a variety of different truss configurations.