A Nationwide Internet-Based Engineering Design Contest for K-12 Outreach

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Purpose

This paper describes the development and ongoing implementation of the West Point Bicentennial Engineering Design Contest—a nationwide competition for K-12 students, to be conducted during Academic Year 2001-2002. The concept for the contest is unique, in that students will register, enter, have their entries judged, and receive performance feedback entirely via the Internet. In this paper we describe the contest goals and the planned sequence of events. We then discuss the unique challenges in software development, website development, and contest administration that have been addressed throughout the planning process. We conclude with an assessment of the prospects for successful implementation of the contest in the coming year.

Background

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 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." [1]

Today USMA is preparing to celebrate the 200th anniversary of its founding. As part of the celebration, the Academy will commemorate its proud engineering heritage by conducting a nationwide engineering design contest for K-12 students.

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. Given the nature of the proposed project, responsibility for detailed planning and implementation of the contest fell to the USMA Department of Civil and Mechanical Engineering.

Goals and Objectives

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, we have developed the following specific objectives for the contest:

- 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.

The Concept for the Contest

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. And 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.[2,3,4] Furthermore, by their very nature, these sorts of competitions tend to be exclusionary. For example, Odyssey of the Mind permits a school to enter only one team for each of five design problems. The FIRST competition requires a $4,000 entry fee, upwards of $10,000 in additional investment, and direct involvement by practicing engineers or university students and faculty. 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 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 at all, it is generally not informed by math or science, and it is seldom iterative. In such projects, model bridges are loaded to failure, but there is often no opportunity for the student to understand why the failure occurred or how the design might be improved. As

such, 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—one 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 revised concept is illustrated in the following sequence of events:

- 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.

To provide a strong incentive to participate, the contest will offer substantial prizes—scholarships of $15,000, $10,000, and $5,000 for the first, second, and third place winners, respectively.

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. The remainder of this paper describes the challenges we encountered and how we addressed them—in most cases successfully.

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 student 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)[5] and in References 6 and 7.

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—and 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.

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 it as such, 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. This feedback has been instrumental in improving 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 Cooper's goal-directed principles for user-interface design.[8]

Eligibility and Rules

Having developed the West Point Bridge Designer and thus demonstrated the viability of an Internet-based contest, we were able to develop of a consistent set of contest rules. To a large extent, this process consisted of posing and answering a series of fundamental questions, the most important of which are as follows:

- ***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.
- ***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 two 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 highly 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, such 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.

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

Development of the Contest Web Site

As the discussion above suggests, many of our decisions about rules and eligibility have had a substantial impact on the structure and function of the contest website. Thus we could not develop the site until the rules were firmly established.

The site itself consists of two major components: (1) a "front end," which presents an overview of the contest, the rules, a page for downloading the West Point Bridge Designer, and a page for reporting problems; and (2) a "back end," which provides for contest registration, design submissions, and automated judging. The "front end" is written in standard HTML. Because it serves only to provide contest information, it is currently accessible at http://bridgecontest.usma.edu/. The "back end," though fully implemented and tested, will not be accessible until the contest begins on November 11, 2001.

The "back end" of the web site represents the most unique aspect of the West Point Bicentennial Engineering Design Contest. It consists of a hand-coded secure Perl script that:

- requires the entrant to certify the eligibility of the "team" (which might be one or two students);

- prompts the entrant for a team name (which serves as a User ID) and password;
- prompts the user for all required registration information, then posts that information to the contest database; and
- provides an opportunity for the team to upload a completed design for judging.

Once a team is registered, it may log in to the site and submit a design at any time during the Qualifying Round. When a design is submitted, the website:

- checks that the submission is a valid West Point Bridge Designer data file;
- checks that no identical design has been previously submitted;
- rejects the submission (and informs the entrant), if the design is invalid;
- calculates the cost and validates the load-carrying capacity of the design, if it is valid;
- determines the current standing of the entry, and reports it to the entrant; and
- posts the team name, school, and submission date to the Scoreboard, if the team's standing is in the current top 40.

The Learning Activities Manual

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 numerous middle-school and high-school teachers suggests that there is strong demand for just such 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 lesson plans that tie the Bridge Designer software to a hands-on bridge-building project. The five lesson plans are compiled in a Learning Activities Manual that will be mailed to the Technology Coordinator at every high school in the U.S. and posted on out contest website in February 2001. The five learning activities provided in the manual are:

(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 their classroom instruction in a meaningful way.

Budget and Funding

The total budget for the West Point Bicentennial Engineering Design Contest is $700,000, which includes allocations for the salary of one part-time staff member, purchase of a web server, contest publicity, prizes, travel and lodging for the six contest finalists, development and

distribution of the Learning Activities Manual, and minor administrative costs. Development of the West Point Bridge Designer and the contest web site were accomplished by the authors, at no cost to the project.

The contest is now fully funded, largely because of a happy coincidence—the 150th anniversary of the founding of the American Society of Civil Engineers (ASCE) also occurs in 2002. Recognizing the potential value of the contest in supporting its own 150th Anniversary educational outreach program, ASCE has signed on as the primary sponsor of the West Point Bicentennial Engineering Design Contest and has generously contributed $250,000 to the project. Other private donors have contributed an additional $35,000, and the remaining funds have been provided by the Department of the Army, in recognition of the potential value of the contest to the West Point admissions program.

Publicity and Local Support

Publicity for the West Point Bicentennial Engineering Design Contest began in October 2000, with the publication of a contest brochure and activation of the contest website. The website is currently averaging approximate 500 unique hits and 150 downloads of the West Point Bridge Designer per day. In addition, a variety of national and local media events are planned to publicize the contest in the coming year.

Perhaps the most important form of contest publicity, however, will come from local grass-roots support, provided by engineering practitioners from the American Society of Civil Engineers and volunteers from West Point alumni organizations. ASCE has already identified a slate of "champions" from its local Sections and Branches—volunteers who will be visiting schools, working with students and teachers, and organizing local media coverage. In the end, this grass-roots promotional effort may be the most valuable benefit of the West Point-ASCE partnership.

Assessment and Prospects for Success

As planning for the contest has proceeded, we have attempted to continuously assess every aspect of the project and to adjust accordingly. At present, the prospects for success appear to be quite good, though much work remains to be done. Specific positive indicators include the following:

- Our ability to obtain full funding for the contest from a variety of sources is a strong indicator that the goals of the project are valued and the concept is viable.
- Our partnership with ASCE greatly enhances the stature of the project and provides an important source of grass-roots support from engineering practitioners.
- 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 Bridge Designer has been formally endorsed as an educational tool by the Educational Activities Department of ASCE. And 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 believe that the positive reputation of the software among secondary school educators will contribute significantly to the legitimacy of the design contest.

- The success of our manually maintained "Best Scores" web page further supports the viability if an Internet-based competition.
- In November and December 2000, we conducted a test contest with four local high schools. The principal purpose of this exercise was to test the functionality of the contest website—both the "front end" and a beta version of the "back end." Students from the four schools were asked to register for the contest, download the West Point Bridge Designer, design one or more bridges, and submit their designs to the test website for judging. Throughout the test contest, the website worked flawlessly. The registration process functioned smoothly, and student submissions were evaluated and posted to the scoreboard without error. The feedback we received from teachers and student participants was enthusiastic and constructive.

We currently have only two major concerns about implementing the contest:

- Thus far the contest website has only been tested with a small number of users. Its functionality has been effectively validated, but its ability to handle a large volume of traffic is still open to question. We will be running a larger-scale local test in the months ahead to address this concern.
- The only negative feedback we have received about the contest thus far concerns the lack of a Macintosh version of the West Point Bridge Designer. This criticism is both valid and quite significant, since a large proportion of secondary schools are equipped only with Macintosh computers. At present we do not have a fully satisfactory solution to the problem. Neither our timeline nor our project budget will permit the creation of a Macintosh version of the West Point Bridge Designer. We are currently evaluating the use of Virtual PC—a Macintosh-based software package that emulates Windows and allows Windows programs to be run on a Macintosh computer. The results of our preliminary tests are promising.

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