Using Information Technology to Facilitate Accessible Engineering Outreach on a National Scale

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Introduction

This paper presents a description and comprehensive assessment of the West Point Bridge Design Contest—a nationwide, Internet-based competition that has provided an engaging introductory engineering experience to over 40,000 high-school and middle-school students in the past three years. We begin by discussing how existing national engineering competitions have influenced the development of our contest infrastructure—a specially developed simulation software package and a web-based judging system. We briefly describe the implementation of the contest and present a comprehensive assessment of the extent to which it is accomplishing its goals. The assessment results serve as the basis for conclusions about the viability of IT-enabled engineering outreach.

Goal

The principal goal of this project is to increase *awareness of* and *interest in* engineering among a large, diverse population of middle-school and high-school students. By making engineering accessible to a broad audience, we seek to overcome students' common misperception that engineering is an endeavor for the "technically elite." [1]

We suggest that this goal can be achieved by creating an authentic, engaging engineering design experience; by offering the experience as a competition that will capture and hold students' attention; and by ensuring that the design experience is readily achievable by *any student* in the target population, while still presenting a challenge to those who are already technologically inclined.

The Influence of Other Engineering Competitions

Using a national competition to promote science and engineering is by no means an original idea. The Science Olympiad, the FIRST Robotics competition, the Junior Engineering Technical Society (JETS) National Engineering Design Challenge, the Future City Competition, and Odyssey of the Mind have existed for many years and have achieved considerable success.[2-6] Newer contests, like the Smith College Toy Challenge, appear every year.[7] Other forms of outreach, such as direct classroom interventions by educators and practitioners, often incorporate competitions to engage and motivate students.[8]

In developing the West Point Bridge Design Contest (WPBDC), we sought to complement, rather than compete with, these existing competitions—to create a uniquely accessible format that might appeal to students who are unable or unwilling to participate in the other competitions. This goal influenced the design of our contest in four ways:

- Most existing competitions charge a registration or membership fee, ranging from $25 (Future City) to $5000 (FIRST Robotics), and participants typically buy their own construction materials. In developing the WPBDC, we sought a format that would entail *no costs* for participants or schools.
- Existing competitions require each team to build a physical device, structure, or model, which is typically evaluated at local, regional, and national levels. Though entirely consistent with the goal of increasing students' interest in engineering, this format requires an extensive contest infrastructure—a national organization, local and regional contest sites, and a large number of volunteers. (For example, the 2002 Science Olympiad required 45,000 volunteers.) The WPBDC format requires a national-level project team of only three people, and it requires no local or regional infrastructure. Thus the contest is relatively inexpensive to run, and participation does not place exorbitant time demands on already overburdened secondary school teachers.
- Most existing competitions are school-centered; i.e., students form teams and compete under the auspices of a school, often with a teacher as a project advisor. Although this format promotes positive interaction between students and their teachers, it has the indirect effect of excluding students who might want to compete even though their schools have chosen not to participate. The WPBDC is designed, such that *any student* may participate, whether or not school sponsorship exists.
- Although existing competitions use information technology for administrative tasks like registration, only Future City requires competitors to employ the computer as a problem-solving tool. In the WPBDC, we sought to expand the use of information technology to *all aspects of the contest*—problem-solving, registration, design submission, judging, and feedback—thus reinforcing the importance of the computer in modern engineering.

About Model Bridge-Building

In 1995, the planning committee that conceived the WPBDC recommended that the contest involve the construction of physical model bridges. This recommendation made sense, in that a bridge-building activity would fit well with existing elementary and secondary school curricula. For example, Carroll has developed a bridge-building project for the elementary grades,[9] and such projects are ubiquitous in secondary school curricula as well. Many middle school technology curricula include bridge-building modules, and high school physics courses often study trusses as an application of statics. A web search yields information on hundreds of such bridge-building activities, including one international competition.[10]

Most of these projects follow a common format. Students receive materials—usually wood or pasta—and are asked to build bridges with a prescribed span length. The completed structures are weighed, load-tested to failure, and judged by their strength-to-weight ratio. Students undoubtedly enjoy such projects. But to what extent do these model bridge-building activities actually facilitate learning about engineering design?

National technological literacy standards characterize the design process as *systematic, iterative, creative, based on criteria and constraints,* and *purposeful* (meaning that the process culminates with a functioning product or system).[11] The typical model bridge-building project fails on all five counts. The experience is not iterative. It culminates, not with a functioning product or system, but with the destructive evaluation of a single prototype. Students often avoid creative solutions that might prove embarrassing in a public load test. Designs rarely result from a systematic process. Students derive structural concepts from photos or from vague notions of what bridges ought to look like. Designs, if they are developed at all, are seldom informed by math or science. Even the design criterion—maximum strength-to-weight ratio—is unrealistic. Actual bridges are designed to carry code-specified loads safely, at minimum cost. Actual bridges are *never* designed to maximize strength-to-weight ratio.

These inadequacies led us to use computer simulation in lieu of a physical model-building project. This decision is consistent with the work of Harmon and Chung, who have demonstrated that simulations can be used to create authentic design experiences.[12,13] Moreover, computer animations can enhance student engagement, promote visual learning, and enhance the understanding of complex concepts.[14]

The Contest Format

Based on these considerations, we decided to use information technology to facilitate broad participation in the contest, to reduce its cost, and to enhance the realism of the design experience. The resulting contest format is illustrated in the following sequence of events:

- Competing individually or in teams of two, contestants access a website to register for the contest.
- They download the West Point Bridge Designer software and use it to design a bridge, based on specified criteria and constraints.
- They upload the bridge design to the contest website for judging. Bridges that pass a simulated load test are judged based on cost.
- The contest website provides immediate feedback via a dynamically generated web page; e.g., "Your current standing is 375 of 10,467." If the standing is in the current top 80, it is also posted to an online scoreboard—another dynamically generated web page.
- Based on this feedback, the contestants modify the design or create a new one, and then they re-submit it for judging. There is no limit to the number of designs a contestant or team may submit.

To promote collaborative learning, while also ensuring that the ultimate contest winners earn their prizes through their own efforts, the contest is organized into three rounds. During the two-month Qualifying Round, we place *no restrictions whatsoever* on collaboration. During the Semi-Final and Final Rounds, however, only intra-team collaboration is allowed. The top 40 qualifying teams are invited to advance to the Semi-Final Round. Competing at locations of their own choosing, these teams log in to the contest website to receive new design criteria; and they have only three hours to develop and upload their bridge designs. The teams are monitored by on-site contest volunteers, who ensure compliance with the no collaboration rule. The top five semi-final teams then travel (all expenses paid) to West Point for the Final Round. Competing in a public arena, the finalists have two hours to develop new designs. Prizes include $10,000 scholarships for members of the first place team and notebook computers for all finalists.

Implementation of this concept required extensive software and website development, as well as the creation of a consistent set of contest rules. The information technology components of the project are described in the following paragraphs. The rules are posted at http://bridgecontest.usma.edu/rules.htm.

The West Point Bridge Designer

The West Point Bridge Designer (WPBD) software was developed to provide students with a realistic introduction to engineering through the design of a steel truss bridge. WPBD users can:

- graphically create a structural model;
- define the material and mechanical properties of each structural member;
- run a simulated load test to determine if the structure is strong enough to carry a standard, code-specified loading;
- display an animation of the load test, with members color-coded to indicate tension (blue), compression (red), and internal force-to-strength ratios (color intensity);
- modify the design to strengthen any inadequately designed members; and
- minimize the cost of the design, by modifying member properties or structural geometry.

WPBD resembles standard CAD software but has a substantially simpler user interface (Figure 1). Simplicity has been attained by integrating the geometric constraints of the design problem directly into the user interface and by following Cooper's goal-directed principles of user-interface design.[15]

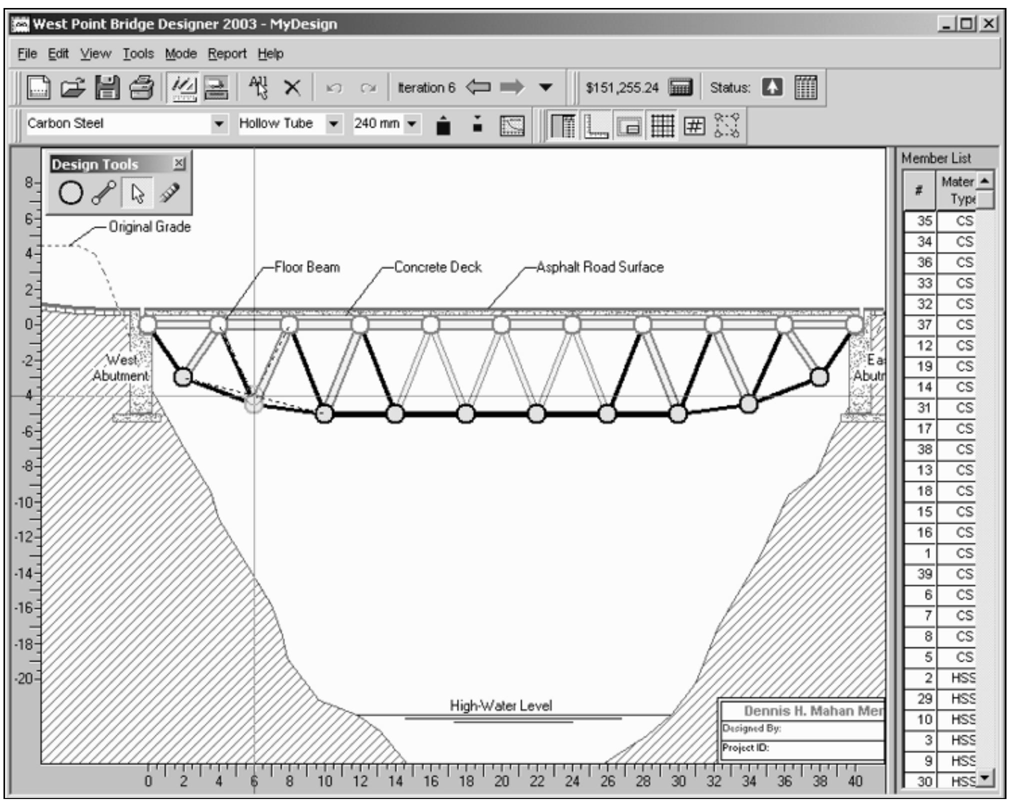

Figure 1. West Point Bridge Designer user interface

WPBD is more than a drawing program, however. Its integral simulation, animation, and cost calculation features enhance the design process by providing real-time performance feedback with a single button-click (Figure 2). Creating a *successful* design—one that passes the load test—is simple. Creating an *optimal* design—one with the lowest possible cost—is quite challenging. Thus, the software offers an engineering design experience achievable by users as young as second grade but still suitable for a national competition involving technologically savvy high-school students.

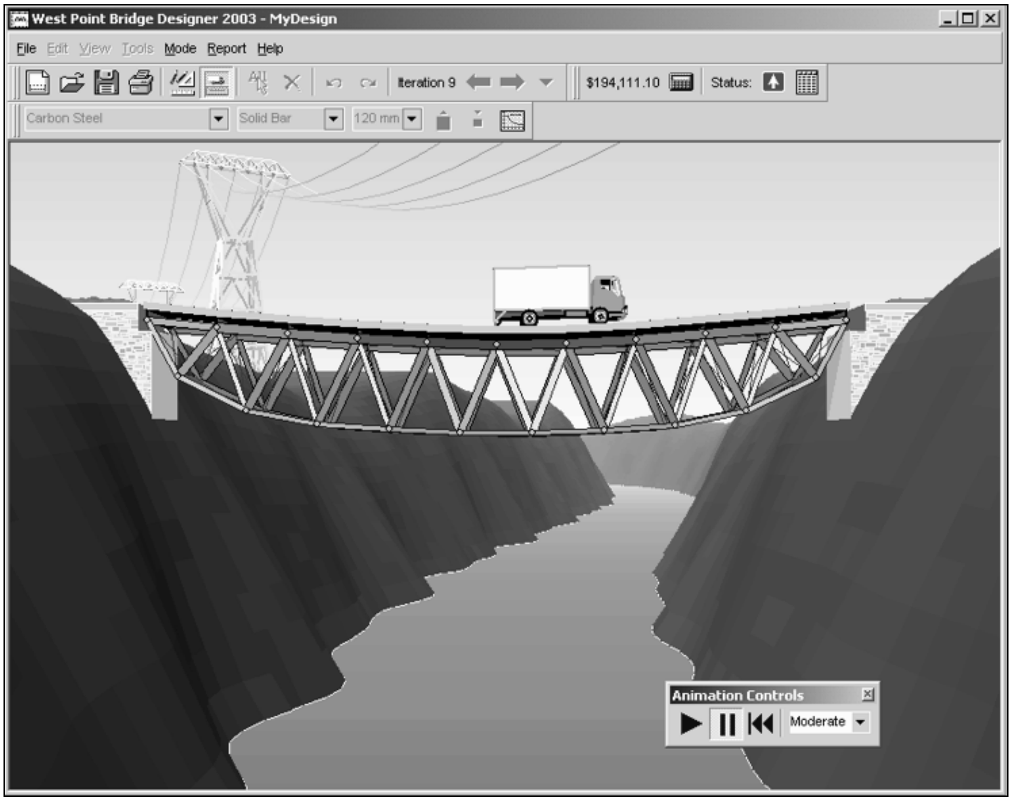

Figure 2. West Point Bridge Designer simulated load test

WPBD directly addresses the inadequacies of physical bridge-building projects. It employs realistic design criteria. It allows students to design iteratively and creatively—to explore many alternatives, orthodox and otherwise. It promotes systematic problem-solving by demonstrating the cause-effect relationship between design changes and structural behavior. As such, WPBD provides teachers with a tool for achieving compliance with both the *Standards for Technological Literacy* and the *National Science Education Standards* (Content Standard E: Abilities of Technological Design).[11,16]

WPBD is a stand-alone Windows application written in Microsoft Visual Basic. Its small distribution size (3.3 MB) facilitates downloads through slow modem connections, which are still common in secondary schools. For additional technical details, see the National Engineering Education Delivery System database.[17] WPBD has been available as "freeware" at http://bridgecontest.usma.edu/download.htm since 1997.

The Contest Website
The contest website consists of two components: (1) static HTML pages providing contest information and WPBD download links, and (2) an integrated contest management system, known as "The Judge."

The Judge is a distributed application that manages team registration, design upload and evaluation, and real-time feedback. When a team registers, the Judge obtains the team members' contact information and asks them to click a button to certify their eligibility. Each registered team receives a "team home page," from which the team can upload new designs, retrieve its current contest standing, and receive special design tips. All three functions are intended to encourage student engagement.

The Judge's evaluation of uploaded designs includes:

- stringent format checks *(nefarious submissions are rejected),*
- a check for previously submitted designs of identical geometry *(duplicates are rejected),*
- validation of the design's load-carrying capacity *(structural failures are rejected),*
- cost calculation *(lower cost results in higher standing)*,
- feedback *(if rejected, the reason for rejection is provided; if accepted, the cost and standing are reported),*
- saving the design in the contest database.

The Judge is implemented as several web applets and a commercial grade enterprise database running on a single four-processor server. In this configuration, it can process approximately 20 bridge uploads per second—more than sufficient capacity for the first three years of the contest. However, many of the applets can be cloned on additional hardware and the database partitioned to increase performance by at least one order of magnitude.

The contest infrastructure includes another applet called the Administrator, which facilitates contest management. The Administrator automatically posts the web-based scoreboard, generates e-mail lists, retrieves individual team data and bridge designs, reports contest statistics, and performs server health and consistency checks.

Project Implementation
Implementation of the WPBDC became a reality when the American Society of Civil Engineers (ASCE) offered to serve as primary sponsor for the event. In addition to a generous financial contribution, the society also supported the contest through its regional sections and branches—by establishing local contests, by sending engineering practitioners into schools to serve as mentors, and by soliciting additional financial support from engineering and construction firms. Thus this project represents a unique partnership between academia, industry, and the nation's oldest professional engineering society.

After six years of planning, coordination, software development, testing, and fundraising, the first West Point Bridge Design Contest began in November 2001 and ended in April 2002. Participation was strong, and the contest ran smoothly. Over 11,000 teams submitted over 54,000 bridge designs for judging. The web technology proved highly reliable, with no processing errors or downtime other than scheduled off-hours maintenance.

From its inception, the WPBDC was envisioned as a one-time event. Yet, even before the 2002 Qualifying Round ended, we had received hundreds of requests from students, teachers, and parents urging that the contest be offered again. Ultimately, we agreed to run the contest annually, subject to continued funding and participation . The 2003 and 2004 contests ran from January to May of their respective years, receiving similarly positive feedback. The total cost of implementation was $156,000 in 2003 and $97,000 in 2004. The decline in funding reflected a sharp decline in corporate donations, resulting from an economic downturn. 2003 contest expenditures included prizes, travel and lodging expenses for finalists, advertising, an awards banquet, and salary for the Contest Coordinator. As a result of the declining project budget, we were unable to purchase advertising for the 2004 contest. The awards banquet was eliminated, and the prize package was cut back sharply.

Project Assessment

In assessing the extent to which this project is meeting its goals, we measured three different outcomes using the assessment instruments indicated in Table 1.

OUTCOME	INSTRUMENT
Extent to which the contest is attracting a large, diverse population of participants	Contest statistics
	Contestant demographics
Extent to which the West Point Bridge Designer is effective as a tool for introducing students to engineering	Statistics on downloads and dissemination
	External evaluations
	User feedback
Extent to which contestants learn about engineering and gain interest in engineering	Student surveys
	Teacher surveys

Table 1. Project assessment—outcomes and assessment instruments

Table 2 summarizes participation in the 2002-2004 West Point Bridge Design Contests, using six different measures.

	2002	2003	2004	Notes
Registered Teams	19,247	18,751	15,198	1
Teams Submitting Designs	11,223	13,477	10,739	1
Individual Eligible Contestants	13,878	16,060	12,951	1
Unique Bridge Designs	54,079	77,653	49,204	1
WPBD Downloads	88,523	134,307	172,305	2
Unique Daily Website Hits	294,790	339,492	345,494	2

Notes:
(1) During the Qualifying Round only.
(2) For the period July 1 to June 30. (2004 data are incomplete.)

Table 2. Summary of 2002, 2003, and 2004 contest participation.

By every measure, participation in the 2003 contest increased significantly from the previous year but then declined back to the 2002 levels in 2004. We attribute the decline primarily to the total lack of advertising for the 2004 contest. It is noteworthy, however, that downloads of the WPBD software and website traffic both continued to increase in 2004—most likely as a result of significantly increased use by university students and international users. Note also that 2004 contestants submitted an average of five designs per team (49,204 design submissions divided by 10,739 teams). Contestants' willingness to create and submit multiple designs suggests that the contest does, in fact, provide an engaging experience.

The demographics of participants in the 2002, 2003, and 20043 contests are illustrated in Figures 3 through 5. These charts show the distribution of contestants by gender (Figure 3), race (Figure 4), and Hispanic origin (Figure 5).

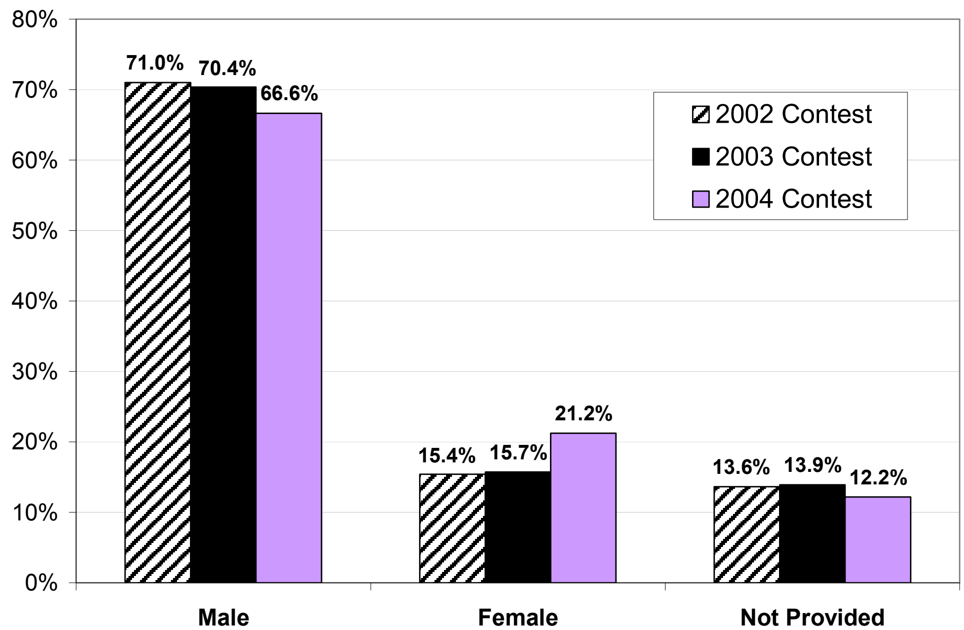

Figure 3. Distribution of contestants by gender.

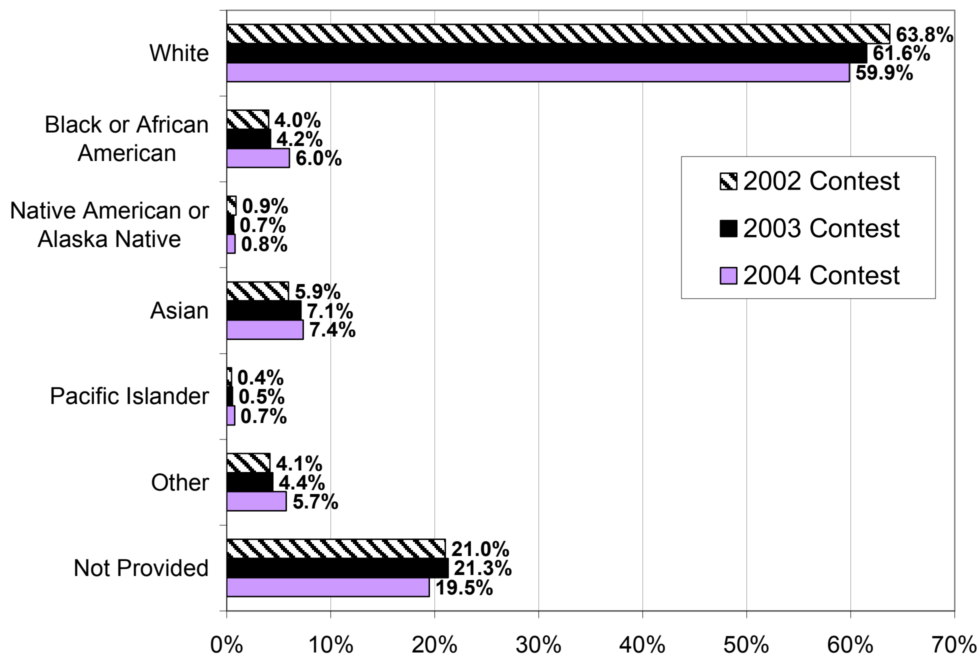

Figure 4. Distribution of contestants by race.

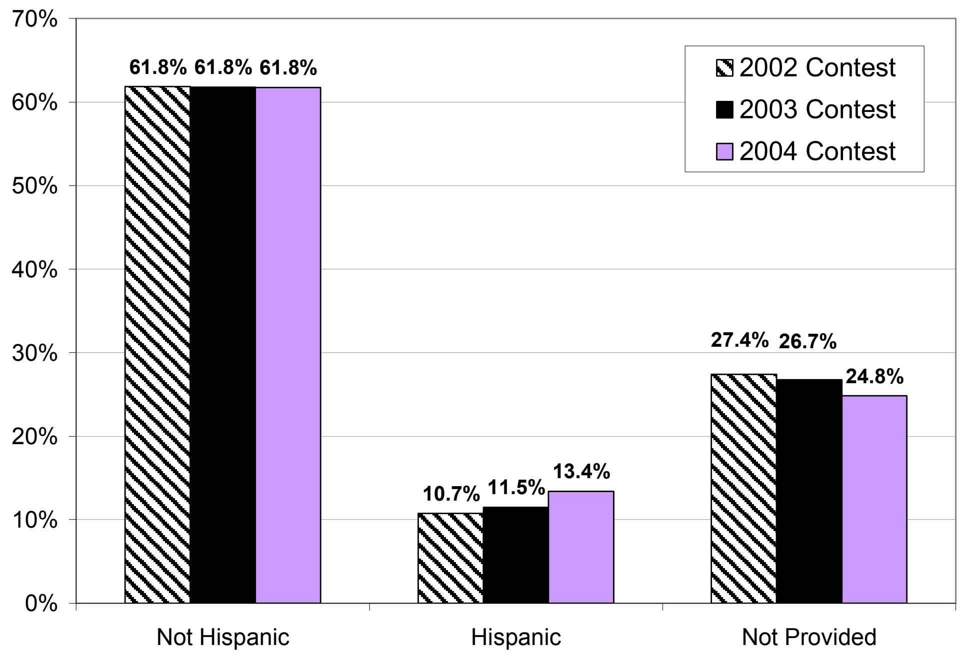

Figure 5. Distribution of contestants by Hispanic origin.

The low percentages of female and African-American contestants are somewhat disappointing; however, the sharp increases in these percentages in the 2004 contest is cause for optimism. Overall, 7158 female, 1944 African-American, and 4898 Hispanic students have benefited from the contest in the past three years.

The geographic distribution of 2004 WPBDC participants is illustrated in Figure 6. On this graphic, each dot represents the zip code of one or more registered contestants. The size of each dot represents the number of participants registered from a given zip code. This graphic underscores the national character of the WPBDC.

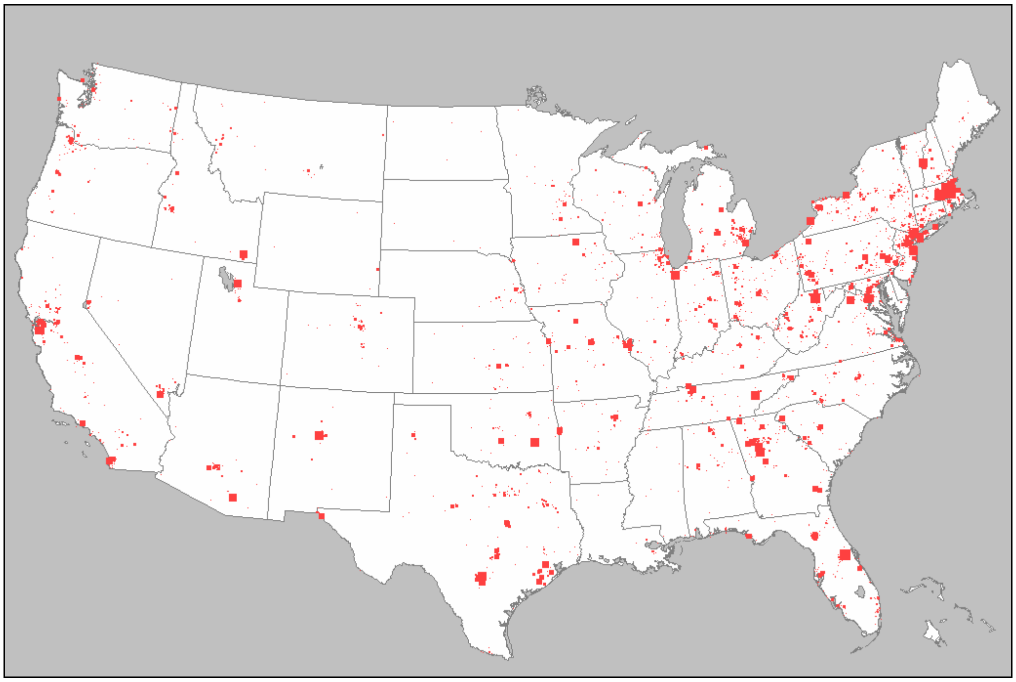

Figure 6. Geographic distribution of 2004 WPBDC contestants.

Assessing the West Point Bridge Designer

Our assessment of the WPBD software is based on three measures:

(1) Dissemination. Over 400,000 copies of the software have been downloaded since October 2000, when we first installed an accurate download counter. We have documented the use of WPBD in over 4,000 middle and high schools and over 100 universities. The software has also gained considerable popularity as an engineering outreach tool, as evidenced in References 18-21.

(2) External Evaluations. In 1999, the Educational Activities Committee of the American Society of Civil Engineers reviewed the software and formally endorsed it as an educational tool. WPBD was also selected for the 2000 Premier Award for Excellence in Engineering Courseware, sponsored by the National Engineering Education Delivery System, John Wiley, and Autodesk.[24] This award was based on a peer review that considered both engineering content and pedagogical design.

(3) User Feedback. In the years since WPBD was first made available, we have received over 1,000 communications from teachers, students, engineers, and parents. Approximately 5% were complaints about the lack of a Macintosh version of WPBD. The remaining 95% were quite positive. Three representative examples follow. These are provided because they illustrate (albeit anecdotally) how the software stimulates learning.

From a high school teacher:
"I think my favorite thing about the program is that it has a really strong appeal for many of my students who are not as academically gifted as Bernard [a high-achieving contestant]. The immediate feedback and graphic display of data got many of the less gifted students excited as well. We installed the program on the library's network, and the librarian reported that students who had almost never set foot in the library before were coming in at lunch and after school to use the program.... It got the students talking about compression, tension, buckling and yielding. They were forced to consider that different materials had different properties, and that different shapes had to be used for different applications. This is coming in very useful, as we are now doing a traditional bridge building contest. I've done this project with students in the past, and I can already see that this year's designs (after working with WPBD) make a lot more sense than in other years."

From a civil engineer:
"I am a bridge design engineer with over 15 years experience.... A few years ago, I read about the bridge designer software in an engineering magazine. I downloaded it and was amazed at how realistic the program depicts the way we do our work.... My 7 year old son was able to successfully design bridges on the computer. He completely understands the process of reducing the cost while maintaining structural integrity."

From a middle-school student:
"I have learned a lot from West Point Bridge Designer 2003. However, I would like to learn much more.... I was just wondering if you could recommend a good Civil Engineering textbook that would help me better understand these concepts."

Assessing Student Learning and Interest in Engineering
To assess the impact of the contest on students' learning and attitudes about engineering, we surveyed contestants and teachers at four schools during the spring of 2003. These schools, described in Table 3, were selected because they represented a variety of regions, grade levels, and student populations--and because each had a supportive teacher who volunteered to assist. These teachers administered our survey instrument to all students participating in the contest. Each teacher also completed a separate survey.

	School A	School B	School C	School D
Location	Lexington, KY	Columbus, GA	San Antonio, TX	Newtown, CT
Total Enrollment	656	1,065	2,500	1,715
Minority Enrollment	32%	27%	45%	5%
Grade(s)	8	9 and 10	11 and 12	11 and 12
Students Surveyed	50	32	35	13
Teacher's Discipline	Technology	Science	Physics	Technology

Table 3. Characteristics of surveyed schools

The student survey included three statements intended to gage the influence of the contest on students' learning about structures, learning about design, and interest in engineering. Students expressed agreement or disagreement with each statement according to a five-point Likert scale.

The results, summarized in Table 4, demonstrate high levels of perceived learning about structures and relatively lower levels of learning about engineering design. Overall, 50% of surveyed students reported increased interest in engineering. These results, though limited by the lack of a control group, are nonetheless consistent with the outcomes reported by Mooney and Laubach in their implementation of "Adventure Engineering" curricula.[1]

	School A	School B	School C	School D
1. WPBD software helped me learn about structures	74.0%	71.9%	77.1%	92.3%
2. WPBD helped me learn about the design process	54.0%	28.1%	31.4%	61.5%
3. Contest increased my interest in engineering	42.0%	59.4%	45.7%	69.2%

Table 4. Percentage of surveyed students responding with "agree" or "strongly agree"

Recognizing the potential inaccuracies in self-reported learning outcomes, our survey instrument asked that students who responded "agree" or "strongly agree" to statements 1 and 2 also list specific concepts they had learned. This question was open-ended; we provided no suggested answers. The responses, which we have characterized and categorized by subject, are presented in Figures 7 and 8.

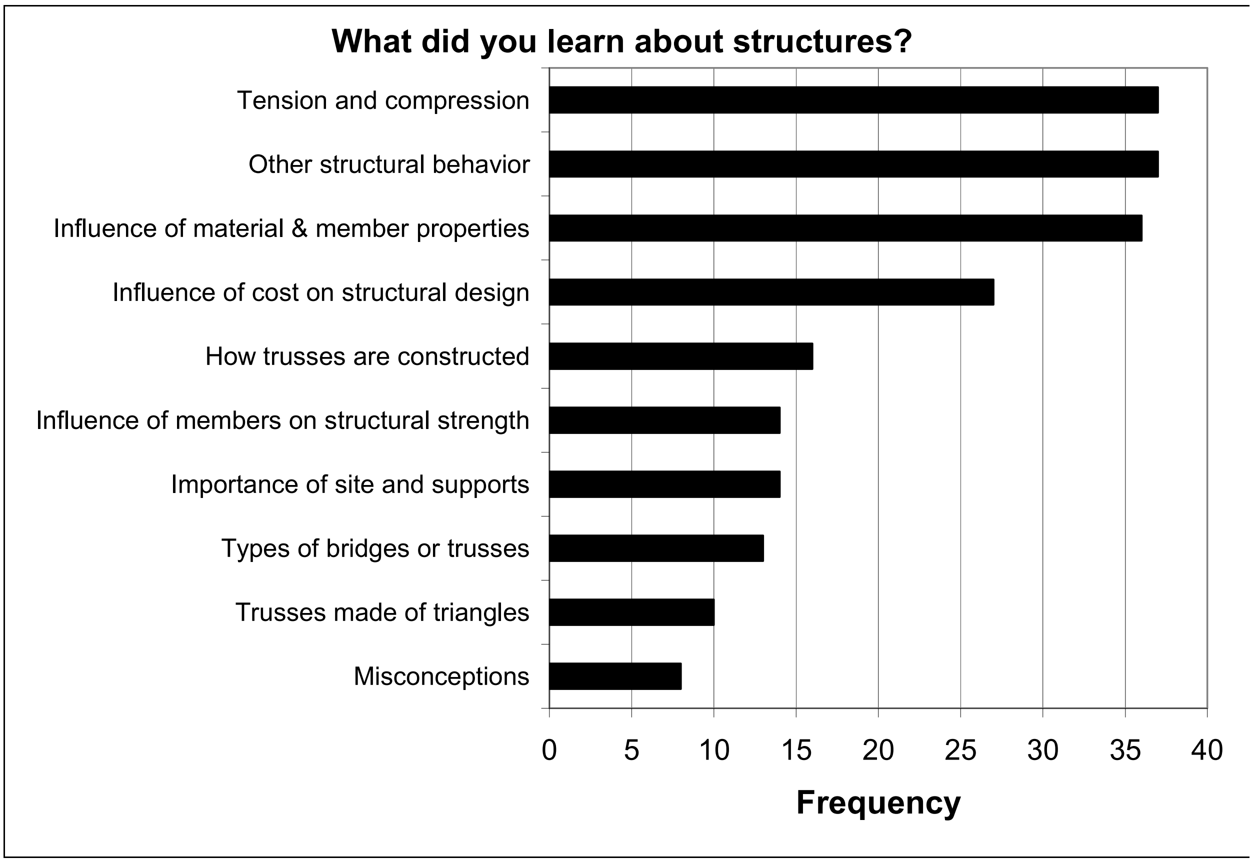

Figure 7. Specific structural engineering learning outcomes reported by contestants.

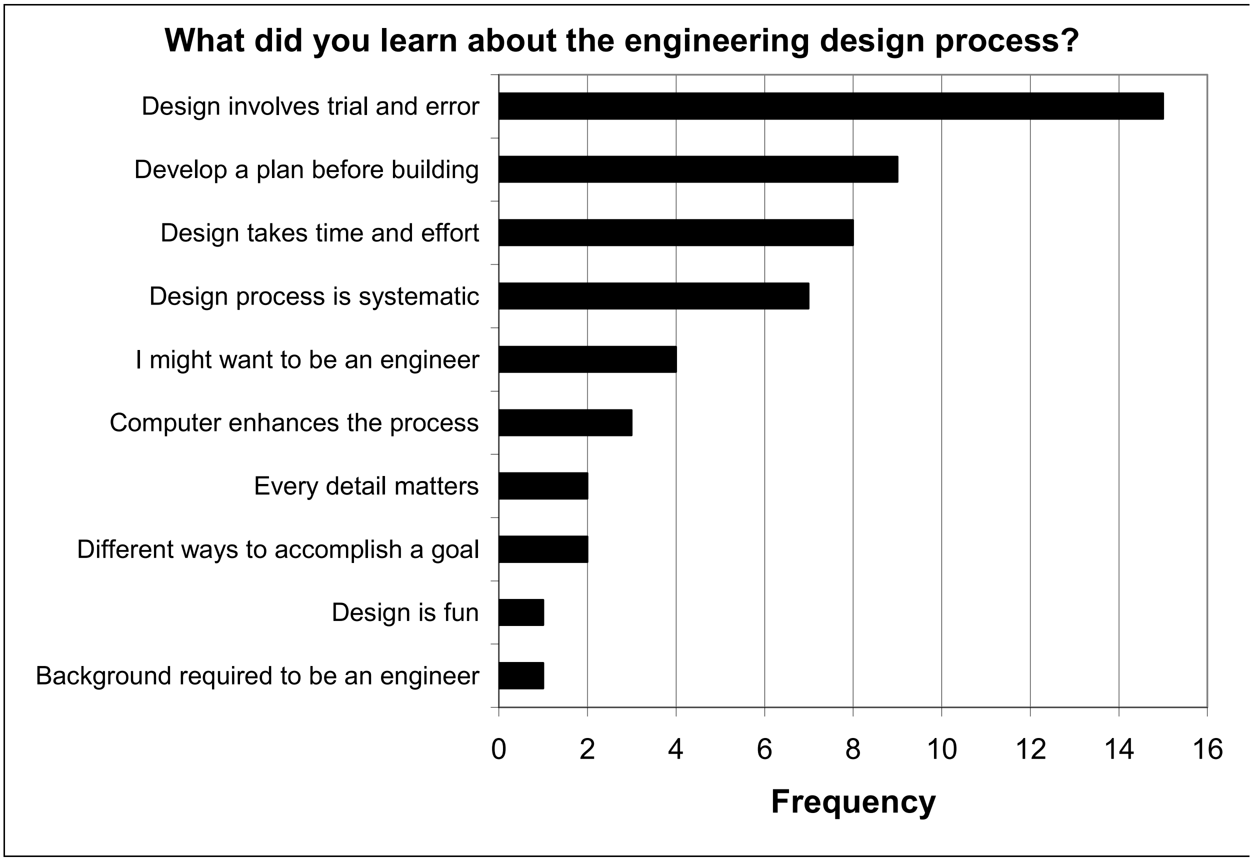

Figure 8. Specific design process learning outcomes reported by contestants.

The process of categorizing responses was necessarily subjective. Nonetheless, the results proved valuable in several ways:

- Although many student responses lacked precision, only 8 out of 267 total responses represented significant misperceptions. (For example, three students incorrectly generalized that arches are stronger than simple spans, whereas there is actually no clear-cut relationship between structural configuration and strength.) The high proportion of accurate observations suggests that the self-assessments summarized in Table 4 are reasonably accurate.
- The learning outcomes reported by the students help to validate the instructional design of the WPBD software. For example, color-coding of tension and compression members, real-time cost calculation, failure simulations, and the iterative nature of the design experience are all reflected in these survey responses.
- The students' misconceptions suggest areas for future improvement of the software.

The survey completed by the four teachers was intended primarily to provide general feedback about the conduct of the contest. We did, however, ask about three specific issues:

What did your students learn from using the WPBD software? The teachers' responses generally paralleled those of their students, except that the teachers added three new (and equally valuable) learning outcomes:

- Students learned the importance of teamwork.

- Students gained confidence in their ability as self-directed learners.
- Students gained comfort with the use of engineering software.

Did the competition have a negative effect on collaborative learning? All four teachers answered no. One noted, "The competition has never prevented collaborative learning. The contest's design probably has a lot to do with this.... The only time I've observed students ignore a request for help from a peer is when they feel like the peer hasn't invested their own time/efforts."

Did the contest enhance your students' interest in engineering? All four teachers answered with an unequivocal yes. One said, "I have students pursuing engineering as a career, or considering the option, who were previously intimidated by the stereotypical image of engineering as nothing more than a burdensome drudgery of equations."

Conclusions

Based on the assessment data presented above, we draw the following conclusions:

- The concept of a wholly Internet-based engineering design competition is viable.
- The format of the West Point Bridge Design Contest—a simulation-based design experience coupled with web-based judging and feedback—can potentially attract large numbers of student participants and can stimulate a high level of engagement.
- By leveraging information technology, a small project staff can deliver high-quality, accessible engineering outreach at a reasonable cost.
- The contest and accompanying simulation software appear to have had a positive influence on students' learning about engineering concepts and on students' interest in engineering.

We also conclude that a similar competition could be developed in *any engineering discipline*, as long as a suitable design problem can be formulated. The key characteristics of the problem are: (1) a very large solution space with no obvious "best answer," (2) a succinct electronic representation of a given design, and (3) design criteria that can be evaluated by a computer program.

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