Using a Nationwide Internet-Based Bridge Design Contest as a Vehicle for Engineering Outreach

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Abstract

The West Point Bridge Design Contest is a nationwide competition intended to increase middle-school and high-school students' interest in engineering. Unique among national engineering competitions, it entails no cost to participants, is entirely Internet-based, and is achievable by any student with a web-enabled computer. By leveraging information technology, a project team of just three people has provided an engaging engineering design experience to over 30,000 students in the past two years. The project receives financial and promotional support from the American Society of Civil Engineers and private industry. Feedback from contestants and teachers indicates that students' interest in engineering is positively affected by their participation in the contest.

I. Introduction

This paper describes a nationwide, Internet-based bridge design competition that has provided an engaging introductory engineering experience to over 30,000 high-school and middle-school students in the past two years. We begin by discussing the problem this project attempts to address. We note the influences of existing national engineering competitions on the development of our contest infrastructure—a specially developed simulation software package and a web-based judging system. We describe the administration, funding, and implementation of the contest and conclude with a comprehensive project assessment.

II. The Problem

Through their role in research, development, and industrial innovation, engineers make disproportionately large contributions to U.S. economic health and national security. These contributions notwithstanding, the U.S. faces a potentially serious shortage of engineers in the near future. According to the National Science Board, the U.S. is unable to keep pace with other countries in the rate at which college-age youth earn science and engineering (S&E) degrees. Six percent of American 24-year olds hold S&E degrees, versus 10% in the United Kingdom and 9% in South Korea. Even as U.S. degree production lags, the number of S&E jobs is expected to increase three times faster than all other occupations in the next decade [1].

To compensate for this shortfall, the U.S. has increasingly relied on foreign-born engineers. In 1999, 10% of U.S. residents holding S&E bachelor's degrees, 20% of those holding master's degrees, and 25% of those holding doctorates were born abroad. This situation produces many economic and social benefits but also entails some risks. First, many critical public sector

engineering jobs require U.S. citizenship [2]. Second, availability of foreign engineers depends on America's attractiveness as a place to live and work. America's relative attractiveness will decline as worldwide economic development increases demand and opportunities for foreign-born engineers in their own countries. Without a commensurate increase in the number of homegrown engineers, U.S. preeminence in science and technology will eventually erode [1].

This problem cannot be solved merely by attracting more American college students into engineering. As Berryman has shown, the talent pool from which we draw our engineers appears in the elementary grades and is fully formed by the 12th grade. After high school, the pipeline to the engineering workforce has many leaks, but no further inflows [3]. Thus, to increase the size of the engineering workforce, we must look to the elementary and secondary grades.

The problem is multi-dimensional, encompassing the distinctly different challenges of increasing students' *proficiency* in math and science, increasing their *awareness* of engineering as a career option, and increasing their *interest* in math, science, and engineering. In responding to these challenges, we must also overcome students' perception that engineering is appropriate only for the "technically elite"[4]. Given its complexity, the problem clearly has no single solution. In the absence of a well-coordinated national program, engineers and educators have responded with a variety of creative approaches [5,6]. We propose another approach here.

III. Goal

The principal goal of this project is to increase *awareness of* and *interest in* engineering among a large, diverse population of middle- and high-school students. In bringing engineering to a broad audience, we seek to overcome students' misperception that engineering is only for the "technically elite."

We hypothesize 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.

IV. Project Development

A. Background

Founded in 1802, the U.S. Military Academy at West Point was America's first school of engineering [7]. In the early 1990s, a committee planning the Academy's bicentennial decided that the celebration should include an event commemorating the institution's engineering heritage. Recognizing the role that early Academy graduates played in building the nation's civil infrastructure, the committee recommended that the event be a nationwide model bridge-building competition for secondary school students. This idea ultimately came to fruition as the West Point Bridge Design Contest. In 1995 S. Ressler assumed responsibility for contest planning. E. Ressler joined the project team in 1999, as the need for computer expertise became apparent.

B. Other Engineering Competitions

Using a national competition to promote science and engineering is by no means a new idea. The Science Olympiad, FIRST Robotics, JETS National Engineering Design Challenge, Future City Competition, and Odyssey of the Mind have existed for years and have achieved

considerable success [8-12]. New contests, like the Smith College Toy Challenge, appear regularly [13]. Other forms of outreach, such as direct classroom interventions, often incorporate competitions to engage and motivate students [14].

In developing the West Point Bridge Design Contest, we sought to complement, rather than compete with, these existing competitions—to create a unique 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 three 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. Our contest entails *no costs* for participants or schools.
- Existing competitions require each team to build a physical device or structure, which is typically evaluated at local, regional, and national levels. Though highly effective, this format requires an extensive contest infrastructure—a national organization, local and regional contest sites, and a large number of volunteers. (For example, 45,000 volunteers supported the 2002 Science Olympiad.) Our project requires no construction of a physical device and, hence, no local or regional infrastructure. Thus the contest does not place time demands on already overburdened teachers.
- 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. We sought to expand the use of information technology to *all aspects of the contest*—problem-solving, registration, design submission, judging, and feedback.

C. Model Bridge-Building and the Design Experience

Early in the development of this project, the bicentennial planning committee recommended that the contest involve model bridge-building—an activity that fits well with existing elementary and secondary school curricula. Carroll developed a bridge-building project for the elementary grades [15], and such projects are ubiquitous in secondary schools 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 hundreds of such bridge-building activities, including one international competition [16].

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 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) [17]. The typical model bridge-building project fails to meet this standard. The experience is not iterative. It culminates, not with a functioning product or system, but with the destructive evaluation of one 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 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.

These inadequacies led us to use computer simulation in lieu of a physical model-building project. Harmon and Chung have demonstrated that simulation can be used to create authentic design experiences [18,19]. Moreover, computer animations can enhance student engagement, promote visual learning, and illustrate complex concepts [20].

D. 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. Contestants:

- Access a web site to register for the contest.
- Download the West Point Bridge Designer software.
- Use the software to design a bridge, based on specified criteria and constraints. (See Appendix A.)
- Upload the bridge design to the contest web site for judging. (The basis for judging is discussed in Section G below.)
- Receive *immediate* feedback via a dynamically generated web page; e.g., "Your standing is 375 of 10,467." If the standing is in the current top 80, it is also posted to a web-based scoreboard.
- Based on this feedback, modify the design or create a new one, and then re-submit it for judging. There is no limit to the number of designs a contestant may submit.

As an incentive for participation, the contest offers $15,000 and $5,000 scholarships for the first and second place winners and computers for all finalists. The scholarships can be used for expenses associated with attendance at any school.

Implementation of this concept required extensive software development, careful formulation of contest rules, and adequate funding. The following sections describe these challenges in greater detail.

E. 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 (see Appendix A) directly into the user interface and by following Cooper's goal-

directed principles of user-interface design [21]. Cooper's principles are most evident in the use of bounded input, pliancy, direct manipulation of drawing elements, and "milestoning" of design iterations. To enhance usability, WPBD allows a structural model to be created, tested, modified, optimized, and recorded *entirely* in a graphical mode—the user can perform these functions without ever touching the keyboard.

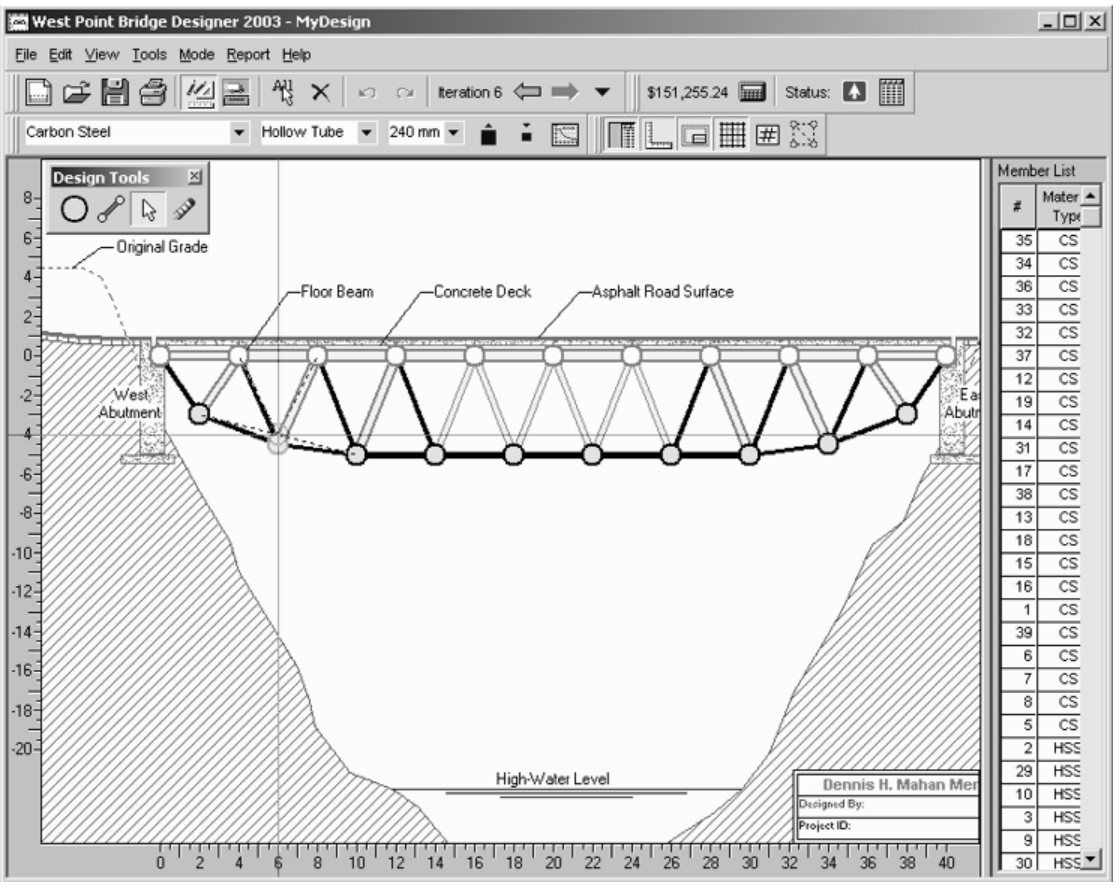

Figure 1. The West Point Bridge Designer user interface

WPBD is more than a drawing program. 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.

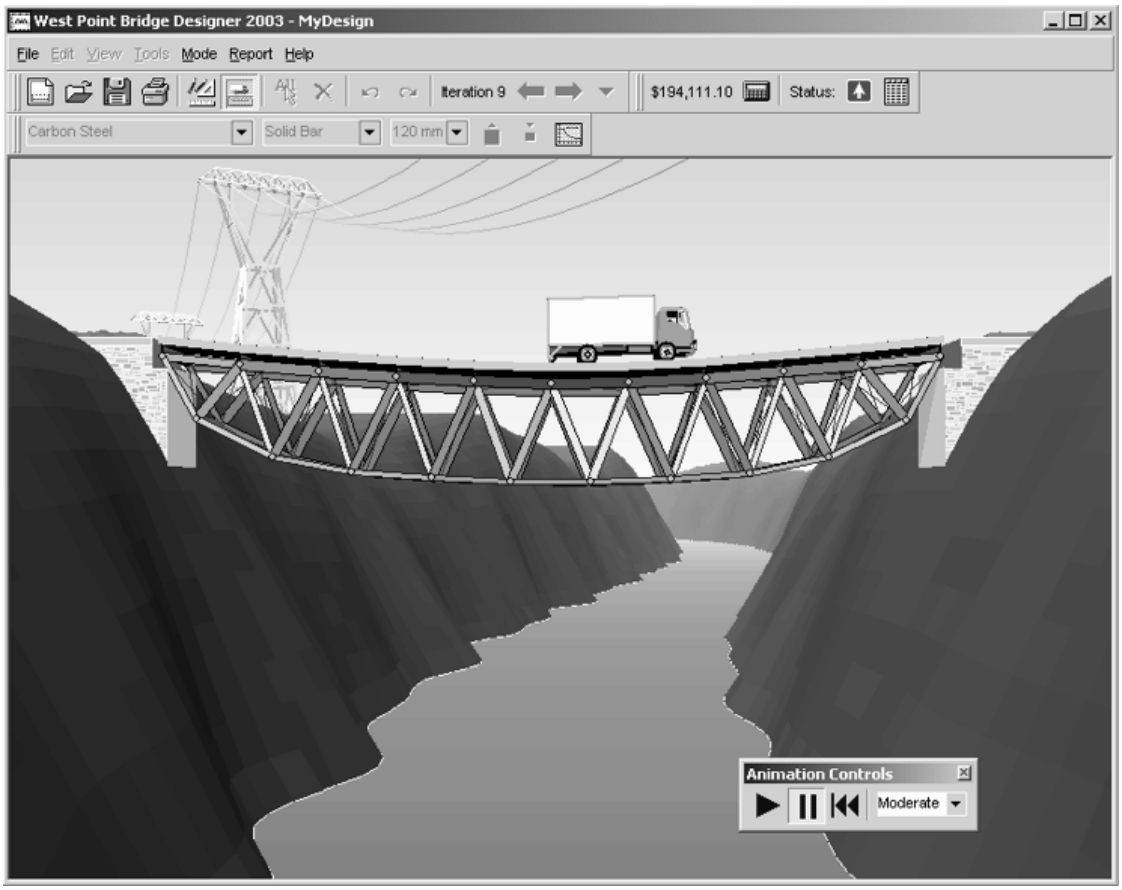

Figure 2. The West Point Bridge Designer simulated load test

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). [17,22]

WPBD is a stand-alone Windows application written in Microsoft Visual Basic. Its small distribution size (3.1MB) facilitates downloads through slow modem connections, which remain common in secondary schools. For additional technical details, see the National Engineering Education Delivery System database [23] and Reference 24. WPBD has been available as "freeware" at http://bridgecontest.usma.edu/download.htm since 1997 and is now used in thousands of schools. (See Section V.B.) Although users have requested a Macintosh version of the software, we lack the expertise to develop one, and we currently lack the resources to fund a Macintosh conversion by a professional developer.

F. The Rules

We designed the contest rules (http://bridgecontest.usma.edu/rules.htm) by posing and answering the following questions, within the framework of the project goals:

Who should be eligible to compete*?* Although the focus of this project was on middle- and high-school students, we initially saw no reason to exclude younger participants. Thus, kindergarteners through 12th graders were eligible for the first contest in 2002. With this decision, we confronted an unexpected challenge—compliance with the federal Children's Online Privacy Protection Act (COPPA). COPPA requires written parental consent before personal information (e.g., address and phone number) may be obtained online from children under age 13. We found that managing thousands of paper parental consent forms was both burdensome and inconsistent with our web-based contest format. In subsequent years, we have restricted eligibility to students age 13 and older. Younger students may still enter an "Open Competition," in which they submit designs and receive feedback but are ineligible to win prizes. Open competitors are not asked to provide personal information.

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 individual students who are unable to find a teammate. We decided to allow students to compete individually *or* in teams of two—but to award prizes in a manner that encourages team participation.

Should collaboration be restricted? To ensure fairness, it is essential that contest winners earn their prizes through their own efforts—an end that can only be achieved by preventing contestants from collaborating with anyone outside of their respective teams. However, restrictions on collaboration are highly undesirable from an educational perspective. To address this dilemma, we have organized the contest into three rounds. During the three-month Qualifying Round, we place *no restrictions whatsoever* on collaboration. During the Semi-Final and Final Rounds, however, only intra-team collaboration is allowed. During the semi-finals, the top 40 teams receive new WPBD design criteria and have only three hours to develop and upload their bridge designs. Competing at locations of their own choosing, these teams are monitored by on-site contest volunteers. 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. The top two teams are declared the winners. This three-round structure promotes collaborative learning during the three-month period in which *all contestants* participate, while ensuring fair and accountable recognition of the winners.

How will we know that a contestant is really eligible? We address this issue by having contestants certify their eligibility during registration. We also verify the semi-finalists' eligibility by calling a teacher or administrator at each of their schools.

What if identical designs are submitted by two different teams? Here we impose 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 claimed the idea first. This policy is advantageous, in that it can be enforced automatically, it encourages teams to enter early, and it virtually eliminates ties.

Will ineligible users enter fraudulently? We anticipated that people who are ineligible for the contest might register fraudulently, providing fictitious personal data in order to obtain feedback about their standing. To avoid the potential administrative problems associated with fraudulent registrations, we provide an Open Competition in which *anyone* can upload designs and receive feedback—without providing any personal information. Open competitors are not eligible for prizes.

G. The Contest Web Site

The structure and function of the contest web site (http://bridgecontest.usma.edu/) were heavily influenced by our decisions about rules and eligibility. The web site 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 following information and saves it in the contest database:

- team name and password,
- name(s) of team member(s),
- certification of eligibility,
- e-mail, postal, and telephonic contact information, and
- optional demographic information.

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; if accepted, the cost and standing),
- saving the design in the contest database.

The Judge has been 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 two 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 official scoreboards after the Contest Coordinator has verified appropriateness of team names and administrative data. It generates e-mail lists, retrieves individual team data and bridge designs, reports contest statistics, and performs server health and consistency checks.

H. Project Team and Funding

The project team for the West Point Bridge Design Contest consists of three people—the authors and a Contest Coordinator. The authors perform all software development, web site management, and server setup and maintenance. The coordinator handles contest administration, day-to-day operations, logistics, purchasing, financial management, and publicity.

Table 1 shows the budget for contest development and implementation. The steady-state cost for implementing future contests is approximately $160,000 per year.

BUDGET CATEGORY	DEVELOPMENT	IMPLEMENTATION	
	1999-2001	2002	2003
Contest Coordinator's Salary	$100,000	$54,000	$32,000
Travel & Administrative Costs	$9,000	$3,000	$2,000
Hardware/Software	$38,206	$10,000	$1,000
Advertising/Publicity	$29,000	$98,000	$20,000
Prizes & Finalist Travel	---	$117,000	$83,000
Final Round & Awards Banquet	---	$38,000	$18,000
TOTALS	**$176,206**	**$320,000**	**$156,000**

Table 1. West Point Bridge Design Contest Budget

Project funding resulted, in part, from a happy coincidence: the American Society of Civil Engineers celebrated its 150th anniversary in 2002—the same year that West Point celebrated its bicentennial. Having already made educational outreach a centerpiece of the 150th anniversary celebration, ASCE contributed $250,000 to become the primary sponsor of the 2002 West Point Bridge Design Contest. Corporate and individual donors added $35,000, and the Department of the Army provided the balance.

Army funding, which was associated with the West Point bicentennial, ended at the conclusion of the 2002 contest. Thus the 2003 contest was funded entirely with private donations. ASCE again served as primary sponsor, providing $75,000. Individual and corporate donors furnished the balance.

ASCE's contributions to the project have extended well beyond funding. The society has energized its regional sections and branches, whose members have visited schools, mentored teams, arranged media coverage, and established local bridge design competitions in conjunction with the national contest. Given our limited advertising budget, this support has proved invaluable.

I. Project Implementation

After six years of planning, coordination, software development, and testing, 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. A few minor disputes with contestants were easily handled within the framework of the published rules.

From its inception, the West Point Bridge Design Contest 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. ASCE also urged continuation of the project and pledged financial support for a 2003 contest. Ultimately, we agreed to run the contest annually, subject to continued funding and participation . The 2003 West Point Bridge Design Contest ran from January to May 2003, receiving similarly positive feedback. The 2004 contest is currently underway.

V. 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 2.

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 2. Project assessment—outcomes and assessment instruments

A. Assessing Contest Participation

Table 3 summarizes participation in the 2002 and 2003 West Point Bridge Design Contests, using six different measures.

CRITERIA	2002	2003	Change
Teams that registered and submitted bridge designs	11,238	13,477	+19.9%
Individual eligible contestants (Age 13 – Grade 12)	13,878	16,151	+16.4%
Schools attended by registered contestants	*	3,900	---
Unique bridge design submissions	54,107	77,653	+43.5%
West Point Bridge Designer downloads	52,013	78,590	+51.1%
Unique daily web site hits	180,111	200,274	+11.2%

*Schools were not counted in 2002.

Table 3. Summary of 2002 and 2003 contest participation.

By every measure, participation in the 2003 contest increased significantly from the previous year, despite substantially reduced funding and minimal advertising. Other more well-established competitions have taken many years to achieve similar participation. FIRST Robotics started with 28 teams in 1992 and has now grown to 800 teams (24,000 students) [25]. The Science Olympiad started small in 1985 but grew to 14,000 teams by 2003 [8]. It is apparent that our Internet-based contest format facilitates rapid growth.

Note that each team uploaded six designs, on average, in the 2003 contest. Contestants' willingness to create and submit multiple designs suggests that the contest provides an engaging experience.

The demographics of participants in the 2002 and 2003 contests are illustrated in Table 4, which shows the distribution of contestants by grade, gender, Hispanic origin, and race. Table 5 shows the distribution of 2003 contestants by race, compared with the U.S. population in 2000 [26].

DEMOGRAPHIC CATEGORY		2002 Contest	2003 Contest
Grade	6	2.2%	0.9 %
	7	5.9%	5.7%
	8	16.1%	13.0%
	9	14.6%	16.7%
	10	15.7%	14.2%
	11	20.9%	22.6%
	12	24.7%	26.9%
Gender	Male	71.0%	70.4%
	Female	15.4%	15.7%
	Not Provided	13.6%	13.9%
Hispanic Origin	Not Hispanic	61.9%	61.8%
	Hispanic	10.7%	11.5%
	Not Provided	27.4%	26.7%
Race	White	63.8%	61.6%
	Black or African American	4.0%	4.2%
	Native American or Alaska Native	0.9%	0.7%
	Asian	5.9%	7.1%
	Pacific Islander	0.5%	0.6%
	Other	4.2%	4.4%
	Not Provided	21.0%	21.3%

Table 4. Demographics of 2002 and 2003 contest participants.

CE	2003 Contest	2000 U.S. Census
White	78.4%	75.1%
Black or African American	5.4%	12.3%
Native American or Alaska Native	0.9%	0.9%
Asian	9.1%	3.6%
Pacific Islander	0.7%	0.1%
Other	5.6%	5.5%

Table 5. Normalized distribution of 2003 contestants by race, compared with 2000 U.S. Census data.

The low percentages of female and African-American contestants are disappointing. On the positive side, however, these data represent 4,413 female, 1,167 African-American, and 3,163 Hispanic students who benefited from the contest. We are also mildly encouraged by the slight increases in participation by female, African-American, Hispanic, and Asian students between 2002 and 2003.

B. Assessing the West Point Bridge Designer

Our assessment of WPBD is based on three measures:

(1) Dissemination. Over 290,000 copies of the software have been downloaded since October 2000, when we first installed an accurate download counter. We have documented

WPBD's use in over 4,000 middle and high schools and over 100 universities. It has also gained considerable popularity as an engineering outreach tool, as evidenced in References 27-30.

(2) External Evaluations. In 1999, the ASCE Educational Activities Committee 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 [31]. 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-achiever]. 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."

C. Assessing Contestants' 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 6, 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. At each school, the teacher 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 6. 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 7, 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 [4].

	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 7. Percentage of surveyed students responding with "agree" or "strongly agree"

Recognizing the potential inaccuracies in self-reported learning, 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 3 and 4.

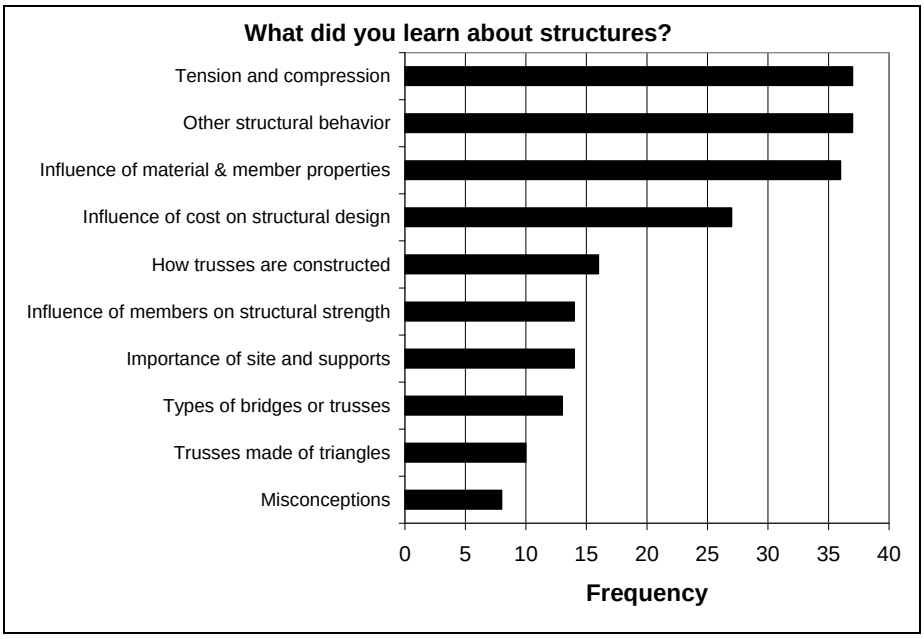

Figure 3. Specific structural engineering learning outcomes reported by contestants.

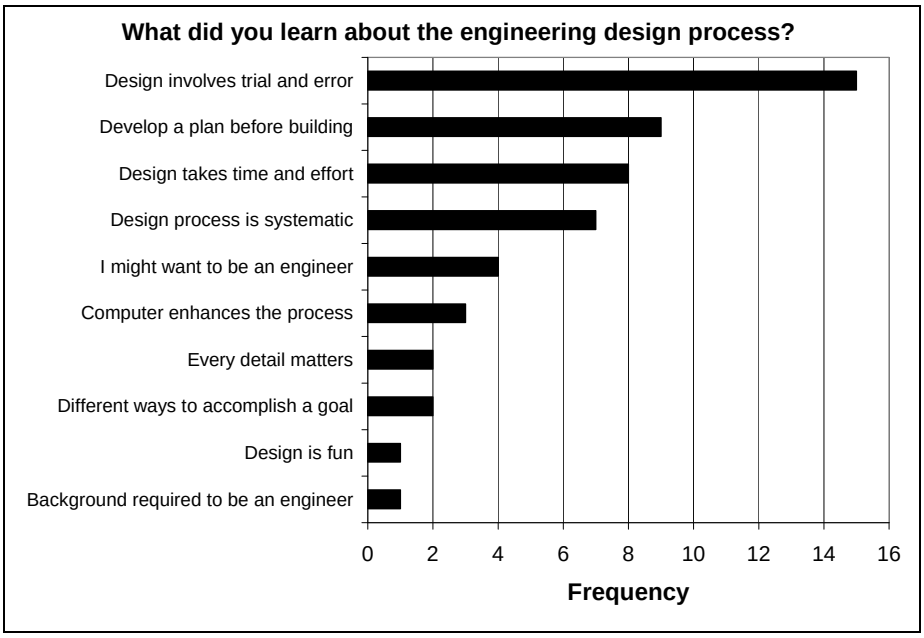

Figure 4. Specific design process learning outcomes reported by contestants.

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 misperceptions. (For example, three students incorrectly generalized that arches are stronger than simple spans.) The high proportion of accurate observations suggests that the self-assessments summarized in Table 7 are reasonably accurate.

- The learning outcomes reported by the students help to validate the instructional design of the WPBD software. For example, the value of failure simulations, real-time cost calculation, color-coding of tension and compression members, and the iterative nature of the design experience is reflected in these responses.
- The students' misconceptions represent areas for future improvement of the software.

To facilitate improved contest implementation in the future, the survey also asked two open-ended questions: "What was the greatest strength of the contest?" and "How could the contest be improved in the future?" The students overwhelmingly cited the greatest strength of the contest as the immediate feedback provided by the WPBD load test animation. This response suggests that the animation feature of the software is critical to the success of the project. In response to the second question, students asked for (1) more choices in the selection of bridge types (e.g., girder, cable-stayed, and suspension bridges, in addition to trusses), (2) more realistic animation graphics, and (3) better instructions on how to use the software. The first two recommendations represent important areas for future development of the contest. The third has already been addressed, in the form of an on-line bridge design tutorial on the contest web site at http://bridgecontest.usma.edu/tutorial.htm.

The survey completed by the four teachers was intended to provide feedback 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."

VI. Conclusion

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 engineering outreach at reasonable cost.
- The contest and accompanying simulation software 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.

Though we are satisfied with the success of this project to date, much work remains. Most importantly, we seek ways to increase the proportion of women and minority contestants, to perform more rigorous assessments of student learning outcomes, and to address students’ desire for more bridge design options and better realism in the WPBD load test animation. Our future efforts will focus in these areas.

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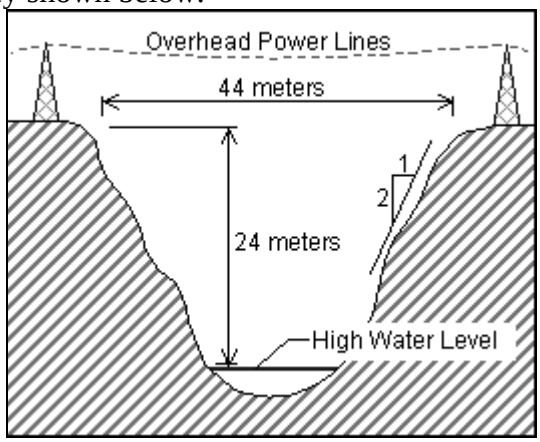
Appendix A – Design Requirement Used in the Contest

1. The Problem. You are a civil engineer working for the state department of transportation. You have been assigned responsibility for the design of a truss bridge to carry a four-lane highway across the river valley shown below.



2. Design Objective. Satisfy all of the specifications listed below, while keeping the total cost of the project as low as possible.

3. Bridge Configuration.

a. The bridge may cross the valley at any elevation from the high water level to 24 meters above the high water level.

b. If the elevation of the bridge deck is below 24 meters, excavation of the river banks will be required to achieve the correct highway elevation.

c. To provide clearance for overhead power lines (shown above), the highest point on the bridge may not exceed an elevation 28.5 meters above the high water level.

d. The bridge substructure may consist of either standard abutments or arch abutments. If necessary, the bridge may also use one intermediate pier, located near the center of the valley.

e. Each main truss can have no more than 50 joints and no more than 120 members.

f. The bridge will have a flat, reinforced concrete deck, 15 centimeters thick and supported by transverse floor beams spaced at 4 meter intervals. To accommodate these floor beams, your structural model must have a row of joints spaced 4 meters apart at the level of the deck.

g. The bridge deck will be 16 meters wide, such that it can accommodate four lanes of traffic.

h. The deck will be covered with an asphalt wearing surface 5 centimeters thick.

4. Member Properties.

a. Materials - Each member of the truss will be made of either carbon steel, high-strength low-alloy steel, or quenched and tempered steel.

b. Cross-Sections - The members of the truss can be either solid bars or hollow tubes. Both types of cross-sections are square.

c. Member Size - Both cross-sections are available in a variety of standard sizes.

5. Loads. The bridge must be capable of safely carrying the following loads:

a. Weight of the reinforced concrete deck.

b. Weight of the asphalt wearing surface.

c. Weight of the steel floor beams and supplemental bracing members (assumed to be 12.0 kN applied at each deck-level joint).

d. Weight of the main trusses.

e. Weight of one standard H20-44 truck loading per lane, including appropriate allowance for the dynamic effects of the moving load. (Since the bridge carries four lanes of traffic, each main truss must safely carry two H20-44 vehicles, placed anywhere along the length of the deck.)

6. Structural Safety: The bridge will comply with the structural safety provisions of the 1994 AASHTO Bridge Design Specification (Load and Resistance Factor Design), to include material densities, load combinations, and tensile and compressive strength of members.

7. Cost Factors. The cost of the design will be calculated using the following cost factors:

a. Material Cost

Product	Cost
Carbon steel bars	$3.15 per kilogram
Carbon steel tubes	$5.04 per kilogram
High-strength steel bars	$4.20 per kilogram
High-strength steel tubes	$6.25 per kilogram
Quenched and tempered steel bars	$5.70 per kilogram
Quenched and tempered steel tubes	$7.95 per kilogram

b. Connection Cost - $150.00 per joint

c. Product Cost - $600.00 per product

d. Deck Cost - $4,050 per 4-meter panel

e. Substructure Cost

Substructure Element	Height	Cost
Standard abutments	-----	$7,050 each
Arch abutments	4 meters	$13,300 each
	8 meters	$17,150 each
	12 meters	$21,100 each
	16 meters	$25,000 each
	20 meters	$29,500 each
	24 meters	$33,000 each
Pier	0 meters	$11,500
	4 meters	$14,000
	8 meters	$16,800
	12 meters	$20,300
	16 meters	$22,800
	20 meters	$25,300
	24 meters	$27,800

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