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Using industry competition to augment student education

- This article discusses the experiences that students from Saint Martin's University in Lacey, Wash., have had participating in the PCI Big Beam Contest for the past three years.
- Experiential learning stages, as they relate to the Big Beam Contest, are discussed.
- Competitions such as the Big Beam contest can improve students' knowledge of precast, prestressed concrete.

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Civil engineering programs are designed to graduate students who are well rounded in all aspects of civil engineering. Still, many students who receive their bachelor of science in civil engineering know relatively little about specialty topics, such as prestressed concrete. Because the civil engineering breadth encompasses multiple disciplines (environmental, transportation, geotechnical, structural) over only four years, students are only required to take classes that focus on the most prevalent topics in each branch of civil engineering. For structural design, this is often limited to building materials such as steel and reinforced concrete. Other topics must be taken as electives, yet elective choice can be limited because of constraints such as alternate-year offerings typical of smaller programs, schedule conflicts, and the number of elective courses a student can add to their already-dense degree requirements.[1] Students who receive a master's degree may be exposed to a wider variety of courses within their field of interest, but they represent only a subset of the larger engineering community.

The unfortunate consequence of having limits to the amount of information that can be transferred to undergraduate students over the course of their studies is that their likelihood of using unfamiliar materials in practice, despite the advantages they may offer, is low. Some exceptions may apply, such as in the bridge industry, where prestressed concrete girders are frequently used in many states.

To develop a working knowledge of a topic not covered by their coursework, students and graduates alike are left with the options of self-education, taking additional courses through universities and other organizations, or perhaps being taught on the job by a more senior engineer. This makes the experience of industry-sponsored student competitions quite valuable. Students can work with university faculty and industry representatives to gain both hands-on experience and a deeper understanding of a given subject.

This article discusses student participation in the PCI Engineering Design Competition, which is more familiarly known as the Big Beam Contest. Students from Saint Martin's University (SMU) in Lacey, Wash., have worked with Concrete Technology Corp. (CTC) in Tacoma, Wash., on entries for the Big Beam Contest for the past three years. A brief discussion of Accreditation Board of Engineering and Technology (ABET) goals and select learning philosophies is included. Big Beam Contest elements are aligned with Kolb's four stages of experiential learning,[2] and a summary of responses from surveys completed by SMU students and industry participants is included.

PCI Big Beam Contest

In an effort to educate and attract young engineers to the precast concrete industry, the PCI Student Education Committee introduced the Big Beam Contest in 2001. Within the competition, students are afforded the rare opportunity to design, detail, fabricate, and test a precast, prestressed concrete beam to failure. Teams are guided through the process by their department professor and a local precast concrete manufacturer. Both the professor and manufacturer can provide unique perspectives related to structural theory and constructibility of the beams. Predictions of the serviceability and strength behavior of the beam are developed and submitted to a present industry representative before the start of testing. Upon conclusion of testing, each team prepares a report and produces a video that discusses the design, fabrication process, and test results. Entries are judged based on material efficiencies, prediction accuracy, and report quality.

The Student Education Committee develops the contest rules. The contest began with a cross section limitation, span length, and center point loading. Students developed their cross section to either maximize load or minimize deflection. Span lengths are set at a minimum of twice the development length of ½ in. (12.7 mm) strand, which is about 14 ft (4.3 m), and a single point load is applied at midspan. Annual adjustments to the cross-section envelope, load configuration, and span length criteria produce unique solutions. In 2005, rules required the students to design and fabricate inverted-tee-beam cross sections. This resulted in large capacities with little deformation prior to failure, the true behavior of this type of element. In 2010, the rules committee incorporated a performance criterion rather than a cross-section envelope. This performance criterion requires teams to meet service and strength requirements. Penalties are applied for sections that deviate from the target requirements. Maximum loading is kept below 40 kip (178 kN) so universities can participate with minimal testing capabilities.

Engineering education

ABET defines 11 "documented student outcomes that prepare graduates to attain the program objectives" for a program to be accredited. In order for civil engineering programs to be accredited, the ABET "Criteria for Accrediting Engineering Programs, 2017–2018" states the following:

> *The curriculum must prepare graduates to apply knowledge of mathematics through differential equations, calculus-based physics, chemistry, and at least one additional area of basic science; apply probability and statistics to address uncertainty; analyze and solve problems in at least four technical areas appropriate to civil engineering; conduct experiments in at least two technical areas of civil engineering and analyze and interpret the resulting data; design a system, component, or process in at least two civil engineering contexts; include principles of sustainability in design; explain basic concepts in project management, business, public policy, and leadership; analyze issues in professional ethics; and explain the importance of professional licensure.*

The American Society of Civil Engineers (ASCE) published *Civil Engineering Body of Knowledge for the 21st Century: Preparing the Civil Engineer for the Future*,[3] which adopts Bloom's taxonomy[4] to describe the minimum cognitive levels. The *Civil Engineering Body of Knowledge for the 21st Century*

Expected levels of achievement for breadth in civil engineering areas and technical specialization

Outcome number and title	Level of achievement					
	1	2	3	4	5	6
	Knowledge	Comprehension	Application	Analysis	Synthesis	Evaluation
14. Breadth in civil engineering areas	B	B	B	B	n/a	n/a
15. Technical specialization	B	M/30	M/30	M/30	M/30	E

Source: Data from Fig. ES-1 in *Civil Engineering Body of Knowledge for the 21st Century: Preparing the Civil Engineer for the Future.*
Note: B = bachelor's degree; E = prelicensure experience; M/30 = master's degree; n/a = not applicable.

cites 15 specific outcomes (similar to the 11 ABET-defined student outcomes) and 6 levels of achievement. The learning path to satisfy the level of achievement is denoted by either B, M/30, or E, which stand for bachelor's degree, master's degree, or prelicensure experience, respectively. As shown in the table, a typical bachelor's program is expected to reach an analysis level (level 4) of achievement for outcome 14, breadth in civil engineering areas. A bachelor's degree will only reach a knowledge level (level 1) of achievement for outcome 15, technical specialization. Exposing students to technical specializations is where industry competitions such as the Big Beam Contest provide a valuable education augmentation.

For this reason, the *Civil Engineering Body of Knowledge for the 21st Century* advises the practitioner to "encourage and support experiential learning." The experiential learning model, as defined by David Kolb, is a four-stage circular learning cycle.[2] The four stages are described as follows:

1. Concrete experience: new experience of situation is encountered or a reinterpretation of existing experience.

2. Reflective observation (of the new experience): of particular importance are any inconsistencies between experience and understanding.

3. Abstract conceptualization: reflection gives rise to a new idea or a modification of an existing abstract concept.

4. Active experimentation: the learner applies them to the world around them to see what results.

Given the interdependency of the learning process, these stages can circle back on each other.

PCI Big Beam Contest aligned with Kolb's four stages

Here we delve into the Big Beam Contest process for the SMU students in conjunction with CTC. The process is roughly separated into Kolb's four stages of experiential learning. By the time stage 4 is reached, it ventures into and overlaps stage 1 and the cycle repeats for subsequent years, thus illustrating the cyclical process of learning and Kolb's stages. The circular nature of the stages is also repeated annually through the passing of information from seniors to juniors and sophomores.

Stage 1: Concrete experience

Prior to participating in the Big Beam Contest, it is expected that most, if not all, students have taken a course on the design of reinforced concrete. More beneficial still is if the team members have taken a course specifically focused on the design of prestressed concrete. In schools that are smaller in size or perhaps do not offer prestressed concrete as an elective, it is inevitable that some of the participating students will have little knowledge of the topic. This gap in knowledge of prestressed concrete fundamentals may be filled in by their department professor, the precast concrete manufacturer, or even their fellow teammates. In some instances, there may also be space in a team for underclassmen to participate in an apprentice role. Students with prior exposure to design classes and the use of concrete as a material tend to benefit the most through the experience.

After a team of students has been formed under the direction of a department professor, all parties gather for an introductory meeting. In this meeting, students are given the opportunity to become familiar with the competition, discuss expectations and schedule, and meet the manufacturer with whom they will be working. It is beneficial if former participants are present to share their experiences and help build excitement. Subsequent meetings can be planned as necessary for the professor or manufacturer to lecture on the use of material models, advanced analysis techniques, and common constructability practices. Many of the analysis assumptions and techniques necessary for success in the competition are beyond the scope of what most undergraduate courses include.

Teams are encouraged to schedule a tour of their local precast concrete manufacturing plant near the beginning of the design process. During the tour, students should take photos, ask plenty of questions, and pay attention to cross sections and reinforcement layouts. Observing fabrication processes and finished products in person can provide the students with a strong starting point in their design.

Saint Martin's University students constructing the form for their beam at Concrete Technology Corp. in Tacoma, Wash., for the Big Beam Contest. Courtesy of Jared Roschi.

Stage 2: Reflective observation

After developing an understanding of prestressed concrete as a material and touring the manufacturing facilities, it is important for the team to gather and assess its experiences so far. Many of the design concepts, constructibility practices, or fabrication limitations seen during the plant tour are new to the students and may require additional consideration before the intersection of knowledge and practice begins to make sense. This process can be aided by a sit-down discussion with the manufacturer at the end of the tour. Many precast concrete manufacturers will gladly provide practicing engineers or student groups a tour of their facilities if asked.

While reflecting on their newfound knowledge, it may also be helpful to review entries from previous years. After publishing competition results, the PCI Student Education Committee makes public the report of the recent winning team as well as the best overall report. All schools can view the winning design and learn from the success of others. Students should keep in mind that every design concept has room for improvement. They should discuss with one another what parts of the design were successful and what can be adapted or improved in the coming competition.

Stage 3: Abstract conceptualization

With competition rules changing each year, students must be able to extend their previous experiences and conclusions to the new set of challenges being encountered. In the case of the Big Beam Contest, many of the annual rule changes affect span lengths, loading configurations, and service or strength requirements. Teams must identify how the changing design parameters affect the overall design of their beam. Each parameter offers unique challenges. For instance, if the span length were increased and the applied loading left the same, beams will need to be designed to accommodate the increase in moment demand; however, there may be instances where the span length and loading configuration change such that the moment demand remains the same but larger deflections will result.

Many of the teams who participate in the competition opt to develop their own spreadsheet or Matlab scripts to aid in the design of the beam. This is both beneficial and encouraged. The process involved in developing and troubleshooting programs helps to deepen the students' understanding of the subject matter and nuances of the various code equations. In addition, if the software is written dynamically to allow for easy design modification, students may use their program to iterate until an optimal solution is reached.

Stage 4: Active experimentation overlapping with stage 1

After agreeing on a final design, the team begins working with its local precast concrete manufacturer. The manufacturer must be given clear guidance in order to develop shop drawings and plan for beam fabrication. Teams are encouraged to develop and send structural drawings that detail the geometry, reinforcement layout, and concrete strength requirements of their beams. The manufacturer translates the structural drawings into shop drawings, the primary method of communicating job requirements with the production crew. Teams are asked to review and approve shop drawings before any materials or formwork are ordered. The process of drawing development and approval is intentionally structured to resemble the typical industry experience. This helps students better

The Saint Martin's University entry for the PCI Big Beam Contest rests in the yard at Concrete Technology Corp. Courtesy of Concrete Technology Corp.

The 2017 Saint Martin's University team poses with its beam prior to testing at the University of Washington. Before testing, students predict cracking load, maximum load, and the corresponding deflection. Courtesy of J. Walsh.

understand the progression of a precast, prestressed concrete job before entering the workforce.

Precast concrete manufacturers typically require a minimum of two weeks from the date of drawing approval to the beginning of production. Additional time may be necessary, depending on the lead time required for material procurement and the availability of production space within the plant. The two-week minimum allows for manufacturers to build custom formwork, fabricate reinforcement, and set up the production area. During beam fabrication, students are encouraged to participate to the extent deemed safe by the manufacturer. This typically means that students observe the strand jacking process; lay out and tie reinforcement; secure the form sides in place; watch the concrete being placed; and participate in making concrete test cylinders.

The 2017 Saint Martin's University PCI Big Beam Contest entry is shown between cracking and ultimate load during testing at the University of Washington. Courtesy of Clarinda Marion.

Although there is no firm rule regarding the age of a beam at testing, most teams strive for a minimum of 28 days between casting and testing. This allows sufficient time for the concrete to reach its design strength. It also allows time to coordinate transportation of the beam to the testing facilities. Beam transportation is usually handled by the precast concrete manufacturer to ensure a safe arrival.

On the test day, student teams arrive at the facility with safety equipment and their predictions for the cracking load, maximum load, and corresponding deflection. Because prediction accuracy is critical for success in the competitions, teams often wait until the day before to break their concrete cylinder specimens. This allows the students to make use of the actual concrete strengths when fine tuning their analysis and predictions. Upon arrival at the test site, predictions are communicated to the PCI representative on-site, which is typically the manufacturer. As testing begins, students keep a close eye on their beam for the development of cracks. The magnitude of load is gradually increased until it has reached the minimum criteria for service capacity. Loading is temporarily paused while the students and PCI representative search for signs of cracking. Once confirmed that no cracking has taken place at the service load level, loading is resumed to cracking and then to the ultimate load, when failure is achieved.

Inspection of the failed beam provides valuable insight that students may not experience elsewhere. The location and direction of developed cracks illustrate the importance of both shear and flexure reinforcement. In addition, after identifying the cause of failure, commonly crushing of the top flange concrete or fracturing of a prestressing strand, students may start to reflect on what assumptions or design considerations may have led to that specific failure mode.

Stage 2: More reflective observation

In the final weeks leading up to the submission deadline, students prepare a professional report that details the design concept and construction process and presents the test data. The report-writing process creates space for students to reflect on what was learned and what can be done differently. Often, teams, with the help of their professors, are able to identify root causes of a significant discrepancy between the performance predictions and test results. In the case of the 2017 competition, the SMU team correctly identified the mistake and verified the assessment with a post-test analysis. A secondary, though important, benefit of preparing the report is improved technical writing, which is a necessary skill of effective engineers and highly valued by prospective employers.

In addition to the written report, students produce a video of the competition process. Teams are encouraged to creatively document their Big Beam Contest experiences from concept to completion. Most teams incorporate member introductions, document the production process, and document the beam

2017 St. Martin's University Big Beam Contest entry Initial predictions and results

	Prediction	Results	Error analysis, %
Ultimate load, kip	34.61	34.88	0.79
Deflection at ultimate load, in.	6.17	5.44	11.89
Cracking load, kip	26.37	24.44	7.30
Total	n/a	n/a	19.99

Note: n/a = not applicable. 1 in. = 25.4 mm; 1 kip = 4.448 kN.

2017 St. Martin's University Big Beam Contest entry post-test calculations following reflection			
	Prediction	**Results**	**Error analysis, %**
Ultimate load, kip	34.61	34.88	0.79
Deflection at ultimate load, in.	5.33	5.44	0.06
Cracking load, kip	24.46	24.44	2.00
Total	n/a	n/a	2.85
Note: n/a = not applicable. 1 in. = 25.4 mm; 1 kip = 4.448 kN.			

Summary of 2017 St. Martin's University Big Beam Contest participant characteristics				
Academic year		2015/16	2016/17	2017/18
First-time participants		6	5	6
Repeat participants		n/a	1	1
Number of students who participated in assessment (participation percentage)		4 (67%)	6 (100%)	3 (43%)
Standing in terms of credits earned at time of participation	Freshman	0	0	0
	Sophomore	0	2	2
	Junior	3	0	0
	Senior	2	3	6
	Graduate	0	1	1
Note: n/a = not applicable.				

test. Of significant importance to the PCI Student Education Committee is that the submitted video include test footage. This allows the committee to independently verify the reported test results. The precast concrete manufacturer is also present at the test to verify its accuracy.

Student and industry sponsor assessments

Sampling of student population at SMU

In total, 11 SMU students voluntarily participated in the Big Beam Contest over three consecutive academic years. All student participants declared civil engineering as their major. Each year there was no incentivized participation by associating it with students' grades. A separate survey was sent to participating industry sponsors. Of the 16 sponsors solicited, nine responded.

Due to an agreement between a local community college and SMU, two of the students in academic year 2016/17 were not officially SMU students, though they were enrolled as SMU students for academic year 2017/18.

Survey results

Of the students who responded, 55.5% had not taken a prestressed concrete elective. One student indicated initial concern about not having taken prestressed concrete but wrote, "My team was exceptional in bringing me up to speed in the why/how of prestressed concrete."

The main reason for participating was to gain prestressed concrete experience, and one student wrote, "The competition also gave me confidence in the integrity of the equations defined in the codes and in the end, I would definitely not feel as competent in the design of concrete, both reinforced and prestressed, if I would not have participated in the competition."

The survey indicated that the most appealing part of the competition for 78% of the students was the subject matter, in addition to "all of the encouragement from professionals. The fact that Concrete Technology Corporation was willing to donate all of the materials, time, facilities, and knowledge to aid us in participating demonstrated, to me, a value in this competition."

One student wrote, "I had not even taken mechanics of materials prior to the competition. However, things like stress-strain diagrams and deflections made much more sense in mechanics of materials having the experience from Big Beam."

Industry sponsors from Florida, Washington, Oregon, New Jersey, Minnesota, Arizona, Iowa, and Ontario responded to the survey. Respondents overwhelmingly indicated that the most beneficial element of participation was the increase in student knowledge of precast and precast, prestressed concrete. By supporting a competition that exposes students to the details of precast, prestressed concrete design and fabrication, manufacturers are ensuring that graduating students are familiar with the industry despite receiving little exposure during their core civil engineering undergraduate coursework. The Big Beam Contest is also commonly viewed as a practical form of community outreach and can provide a beneficial means of connecting with potential candidates for future employment.

Of the nine industry sponsors who responded, eight (89%) had participated in the Big Beam Contest two or more years. Several of these sponsors have been involved in the competition for more than a decade. In academic year 2015/16, one company sponsored three teams, four companies sponsored two teams, and three companies sponsored one team. In academic year 2016/17, four companies sponsored two teams and five companies sponsored one team. The average cost per team sponsored was $5200, with a median cost of $4500. The average distribution of cost is split nearly 50/50 between material and labor. Worth noting is that the cost of participation, while very real, was relatively minimal compared with the perceived benefits.

Potential barriers to participation

Clearly participation in the PCI Big Beam Contest requires a capable industry sponsor in close enough proximity to be feasible for student participation. In addition, a testing facility with adequate capacity is necessary.

Conclusion

Through experiential learning, the PCI Big Beam Contest enables students to develop a *Civil Engineering Body of Knowledge for the 21st Century* technical specialization learning outcome achievement beyond level 1 (knowledge) and easily closer to level 4 (analysis), perhaps even arguably toward level 6 (evaluation). The student survey responses indicate a value for students at all class levels when teamed with upper-level classmates. This provides multiple benefits; the students can learn by teaching each other, learn from each other, and go on in subsequent years to repeat the Kolb learning cycle.

Not surprisingly, both students and sponsors indicate that the highest motivating factor for participation in the PCI Big Beam Contest is increasing students' knowledge of prestressed concrete.

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Abstract

PCI annually sponsors the national PCI Engineering Design Competition, also called the Big Beam Contest. Student teams work with a PCI producer member to build a precast, prestressed concrete beam of a predetermined length. The competition combines design, construction, large-scale testing to failure, direct communication with practicing engineers, and technical report writing. This paper presents a case study of participation by a small private liberal arts institution in the PCI Big Beam Contest. Qualitative data of students' perceptions of the competition is presented, as well as industry partners' cost–benefit analysis of their participation, student perceptions of knowledge gained, and a reflection on how to build on the experience for future participants.

Keywords

Beam, Big Beam Contest, Bloom's taxonomy, competition, construction, design, PCI Engineering Design Competition.

Reader comments

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