THE CONCRETE CANOE ENGINEERING DESIGN COMPETITION

HOW ENGINEERING DESIGN COMPETITIONS AFFECT THE PREPARATION OF ENTRY-LEVEL ENGINEERS

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By
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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

The state of infrastructure in the United States of America is not acceptable. The 2.6 trillion-dollar gap in infrastructure investment could cost the nation 10 trillion dollars by 2039 (American Society of Civil Engineers, 2021). To address this issue, the Biden administration passed the Bipartisan Infrastructure Law in 2021. This program will invest 1.2 trillion dollars into new and existing infrastructure (United States Department of Transportation, 2023). Competent and well-rounded engineers are essential for carrying out the ambitious projects funded by this legislation. Entry-level engineers joining these projects can bring more to the table by getting involved in extracurricular activities while they are students. Testimonies from engineering 'industry experts' support that activities outside of the classroom and practical experiences are what set college graduates apart as job candidates (SolidProfessor, n.d.). A National Institute of Health survey for engineering and business students at Gangwon State University yielded results supporting that extracurricular activities like competitions were highly beneficial for job preparedness (Kang, 2023). This dynamic illustrates the importance of garnering real-world experiences alongside the education received in class.

In 2004, the National Academy of Engineering created a list of traits that engineers must have to address the issues of a world that is rapidly advancing. They described an engineer with these attributes as the *Engineer of 2020*. Some of the traits include analytical skills, communication, and management (Vest, 2005). A 2021 survey of 320 civil engineering undergraduates showed that some social groups believe out-of-class activities, like engineering design competitions, are more effective than what is learned in class to attaining the traits of the *Engineer of 2020* (Polmear et al., 2021). With the Accreditation Board of Engineering & Technology (ABET) desiring 'soft skills' be fostered by engineering students through their education, engineering design competitions serve as an important option for students to build these competencies (Akera, 2016). These competitions are a gateway for applying classroom skills to real-world problems, which is important experience that engineers should have before entering the industry.

For civil engineering students, the flagship engineering design competition is the Concrete Canoe Competition, hosted by the American Society of Civil Engineers (ASCE). Through the last 35 years, over seventy thousand students have competed against each other in this yearlong design challenge (Sulzbach, 2007). Students representing their university's chapter band together to formulate an optimal mix and hull design composed of a suboptimal material. Detailed presentations and high-energy races help judges determine which team has created the best boat for mass-production. Through it all, students gain hands-on experience in project management & engineering design in an environment that simulates a real-world engineering design project. The tasks of the competition are demanding; the Request for Proposal (RFP) is filled with 76 pages of important specifications that details what the owner is looking for from competing teams. ASCE, who provides the RFP, emphasizes the need to read the document in its entirety to ensure that a team's product complies with all requests made by the owner (ASCE, 2023). Like real world projects, teams are penalized and not considered for a project award if they miss a requirement stated in the RFP.

Critical reading and thinking skills are imperative to understanding these kind of documents. Although college curriculums can help develop these skills, studies have shown that undergraduate engineering curriculums do not include enough practice in analyzing engineering text-based technologies that dictate what is and is not allowed when creating infrastructure projects (Barner & Brown 2021). This creates a skill-gap for entry-level engineers that spend a lot of their first working years analyzing and learning the governing codes. Two commonly used structural engineering codes are *AISC 360-16: Specification for Structural Steel Buildings,* and *ACI Code-318: the Building Codes Requirement for Structural Concrete*. They both govern engineering design for building infrastructure that supports life safety. For that reason, it is important that they are well understood and exams for Professional Engineering licensure test on both codes (NCEES, 2022).

Engineering design competitions that require students to examine lengthy specifications provides practice that all engineering students should be getting in the first place. In the context of engineering design competitions, University of Manitoba Dean Ruth said, “don’t miss 50% of your education by attending 100% of your classes,” reinforcing the fact that practical applications of school-taught knowledge are important (Schor & Kakarountas, 2021). Engineering education should be designed to promote these learning opportunities so that future engineers are ready to contribute to the solutions of the world’s issues (Fuchs, 2012). This paper will explore the effects of engineering design competitions on job-preparedness for entry-level engineers.

The Concrete Canoe Competition

The concrete canoe competition was one of the first collegiate engineering design competitions. It set off a spark for the creation of design challenges in other disciplines. The first unofficial concrete canoe competition took place in 1971, when the University of Illinois at Urbana-Champaign and Purdue University held a head-to-head matchup (Bix, 2021). Since then, the competition has received international recognition and become a yearly tradition sponsored by ASCE. This competition takes a canoe, a technology that has already undergone years of innovation, and artificially creates a problem by requesting it be constructed out of concrete. Many of the design elements in a typical canoe are modified to meet this need.

The concrete mix design incorporates lightweight aggregates, admixtures, fibers, and unique cementitious materials to create a mix with a density lower than commercially used concrete. The American Concrete Institute (ACI) defines normal weight concrete as having a density between 135 to 160 lb/ft^3 (2019). It is possible to make a canoe with normal weight concrete, but the resulting weight and dimensions would be impractical. Attaining a density comparable to water's density of 62.4 lb/ft^3 is advantageous, but strength is sacrificed as a result. To design a lighter and more practical canoe, innovative materials like aggregates made of glass spheres or recycled plastic must be researched and tested. To create a winning mix design, tradeoffs to account for weight, geometry and stability must be made.

The hull of the canoe is designed to create a buoyant force strong enough to support the self-weight of the canoe and up to four paddlers. Design choices are also made to minimize opposing drag forces. Existing geometries of typical canoes are useful starting points for design, as they have been perfected over time by previous engineers. For constructability purposes, hull design geometries must be documented via a set of mathematical curve equations (Figure 1). The dimensions of these curves can be inputted into a computer numerical control (CNC) machine, waterjet, or 3D printer to create physical formwork for the canoe. A competitive hull design requires structural analysis to be performed to verify the strength of the canoe. Concepts learned from a typical civil engineering curriculum must be used to perform longitudinal, punching shear, and failure envelope analysis. Additionally, the canoe is analyzed under certain loading cases to identify any shear and moment forces that exceed nominal capacities (Figure 2). By designing the concrete mix and hull properties using these methods, a concrete canoe can successfully float in water and be extremely competitive.

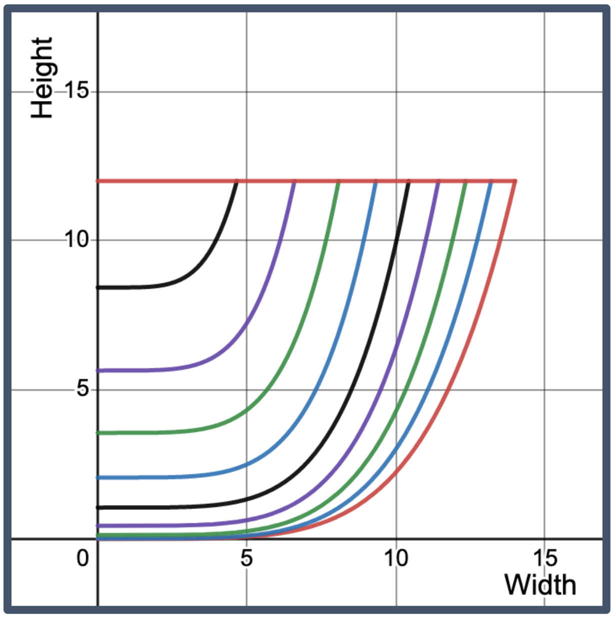

Figure 1. Hull design equations for a concrete canoe (University of Virginia, 2023).

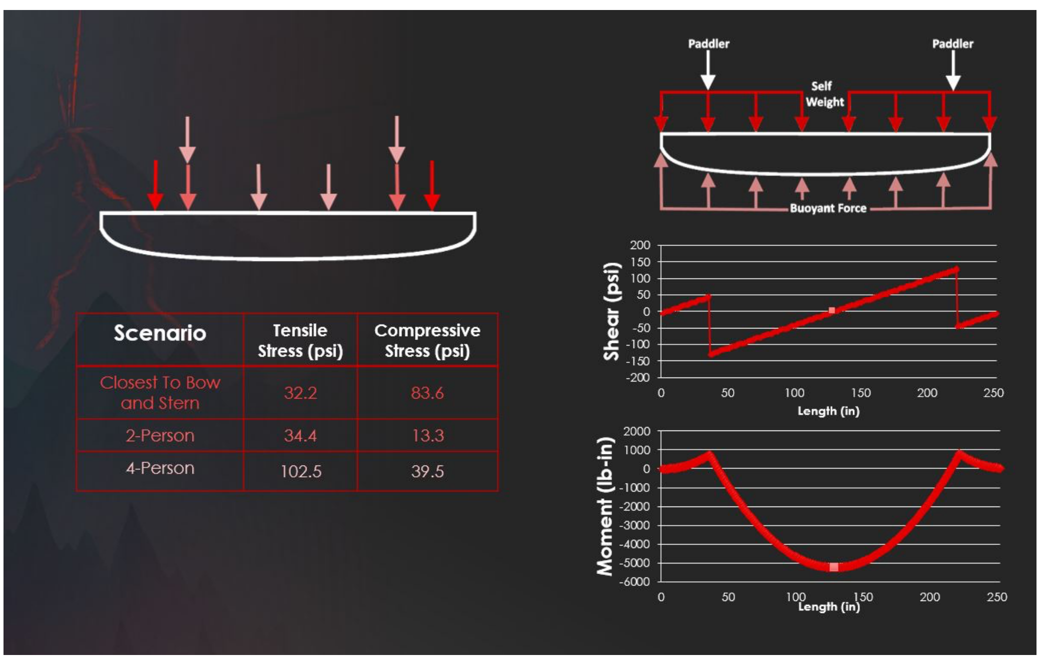

Figure 2. Shear & moment analysis of concrete canoe (Northern Arizona University, 2017).

The design, construction, and management of the University of Virginia's (UVA) concrete canoe will be led by a group of six civil engineering capstone students and supported by 17 other 3rd and 4th year students ranging in fields of study. All their actions are guided by the RFP, which was broken down by the team in the beginning of the process to create schedule items and set personal due dates. From the coordination with a large engineering team to the detailed analysis of the RFP, many activities taking place for this design competition are mirrored in the actual engineering industry. Joining the professional world with these experiences beforehand provides supplementary proficiencies that students otherwise might not have.

Engineering Design Competitions as Infrastructure

Understanding the connection between the concrete canoe engineering design competition and the problem it has the potential to solve for entry-level engineers can be aided by the concept of *infrastructure* by Star (1999). Star defines infrastructure as an embedded technological system that supports the needs of a social group. The uses of a technology are perceived differently between social groups. Some may see them as tools, while others may see them as barriers. Typically, infrastructure embedded within other activities or technologies, and its purpose is served without the groups noticing easily. It is appropriate to analyze engineering design competitions as infrastructure because of the unique ways they serve different social groups. Different social groups, including students, professors, and professional engineers interact with them differently. Additionally, students get the benefits of engineering design competitions by participating in tasks that inherently improve the skills that are sought after by employers.

Star studied infrastructure ethnographically, meaning she inserted herself in a research environment and received first-hand accounts to collect data. With her findings, she created a way to define infrastructure through several different properties. These help with the categorization of different infrastructure systems. Three of those properties that are represented within engineering design competitions are "reach or scope", "learned as part of membership", and "links with conventions of practice".

"Reach or scope" describes how infrastructure has a hand beyond a single use. The benefit of engineering design competitions is that they get students to respect the importance of following codes and directions. Not only that, but their soft skills are improved by contributing to these team-based projects. The reach of this benefit extends past an academic environment into the professional engineering world as well. The "learned as part of membership" aspect illustrates how infrastructure can be interpreted between different groups. In the context of design competitions, those that are involved take advantage of the critical reading skills they form, while others do not. They also get an opportunity to work with different engineering backgrounds, providing an interdisciplinary learning experience that students have reported to be significant (Hill et al., 2020). Finally, the "links with conventions of practice" describes how infrastructure is formed based on existing traditions in a community. With ASCE being a community of civil engineers, they understand the benefits of reflecting the nature of their work in the concrete canoe competition, specifically the act of having to read fine print in requests from the client. This is a skill that engineers need if they want to secure projects. Engineering design competitions are a channel to understand the expectations of the jobs that students will take upon graduation.

Research Question and Method

The exact features of engineering design competitions that contribute to experience-building are not studied in detail. Additionally, it is not clear if the competitions provide more of a technical or social benefit. Some competitions, like the Pacific Earthquake Engineering Research (PEER) sponsored earthquake engineering competitions provide more of a technical benefit by introducing new graduate-level concepts to undergraduates (Brandenberg et al., 2022). Others focus on applying existing knowledge from undergraduate classes to a design challenge, like the concrete canoe competition. This variability raises the following question: How do engineering design competitions affect the preparedness of entry-level engineers?

The technical and social preparedness of engineers must be explored to fully answer this question. The *Engineer of 2020* attributes will be a helpful index for measuring benefits. To answer the question, I will be conducting interviews on entry-level engineers that participated in engineering design competition teams across several universities. Their insight would be helpful in answering my research question because they will provide explanatory evidence that is relevant to present-day circumstances. I will use connections I have made from previous conferences and internships to create a definite list of people to ask. The interviews will not be limited to engineers that participated in the concrete canoe competition. Valuable perspectives can be gathered from students that participate in the ASCE Steel Bridge Competition or other design competitions at the University of Virginia. Broadening the pool of interviewees to other competition participants can provide varying and useful information. Questions I intend to ask include:

1. *"What activities are most memorable from your engineering design competition? What parallels do you see with your current work, if any?"*

2. *“What technical skills or software do you use in your job that you had to use during your engineering design competition?”*
3. *“Can you draw any similarities between team coordination in your current work and that of your engineering design competition?”*
4. *“What skills, soft or technical, do you feel like you still need to improve upon within the next 2-3 years of your career?”*

Explanatory evidence from the interviews will be collected to illustrate if there are benefits of engineering design competitions that resonate with entry-level engineers.

Conclusion

With the issues facing infrastructure today, well-prepared engineers are needed more than ever. However, engineering students cannot rely on curriculum alone to build the technical and social skills they need to effectively contribute to solutions. Engineering design competitions serve as an exceptional extracurricular option to fill the gaps. Data already supports that extracurriculars provide experiences that support soft skills that employers look for from their job candidates. By promoting engineering design competitions, better-prepared individuals will enter the workforce to meet the growing labor gap for civil engineers. The United States can get closer to hitting its goals for infrastructure development faster with well-rounded engineers. It is expected that this research paper will produce results that support that engineering design competitions are an effective extracurricular choice that contribute to helping students feel more prepared for the workforce, specifically by providing a connection between what they learn in class and practical experience.

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