How Engineering Education Can Improve and
How Design Competitions Provide Concrete Solutions

A Research Paper submitted to the Department of Engineering and Society
Presented to the Faculty of the School of Engineering and Applied Science
University of Virginia, Charlottesville Virginia

In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science, School of Engineering

Kenneth Reyes
Spring 2024

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

Advisor
Rider Foley, Department of Engineering and Society

Introduction

Engineering education has a very unique space in education, as it's meant to place special emphasis on teaching the application of scientific principles not the theoretical principles themselves. However, in trying to master these principles the major focus of engineering education can shift far away from real world application and form a gap between a student's knowledge of the theory and their ability to apply that knowledge to real problems. This gap has become a major concern as increasing technological development has shown that the information age will ask new engineers to adapt to a world where technology progresses at an incredible rate. Researchers such as Charles Vest have pointed out "The twenty-first century will be very different from the twentieth. As we think about the challenges ahead, it is important to remember that students are driven by passion, curiosity, engagement, and dreams" (Adams & Felder, 2008 pp. 237). In response, non-formal learning opportunities such as design competitions and design clubs can provide engineers-in-training with a more engaging educational experience.

Extensive research has been done by professionals such as Cindy Rottman that highlights how non-formal learning spaces such as extracurricular clubs play an important role in developing engineering skills, leadership skills, and a love of lifelong learning (Rottmann et al., 2016). Rottman's research suggests that high impact activities can provide engineering students with valuable and practical experiences that can assist in generating a more well-rounded and adaptive engineering leaders of the future. Among those extracurriculars I believe design competitions stand out and offer engineering students a rich opportunity to gain practical experience and shape their understanding of engineering as a profession. Design competitions provide students with an outlet to apply the theories they've been taught in a real-world context.

I want to highlight the Concrete Canoe Competition, in particular, as I believe it exemplifies the potential of design competitions in engineering education. The Concrete Canoe Competition asks a team of engineering students to design and construct a working canoe made entirely out of concrete (Bix, 2019). This unconventional challenge pushed engineering students to think beyond the conventional design and materials that they are taught in class, developing a sense of creativity and out-of-the box thinking. Throughout the competition they are asked to tackle real-world constraints such as budget limitations, material properties misbehaving in the field, structural integrity considerations, cooperation with vendors, and team dynamics. They are tasked with executing the construction of the canoe, racing their canoe for competition, submitting a complete technical report, and an oral presentation of their team's construction process. These presentations are given at the Virginia American Society of Engineers Symposium, exposing students to important professional societies and allowing them to practice communication and presenting, which are critical skills for a professional engineer. The project management, design analysis, and collaboration skills that are core to this competition have been praised by professional engineers as it prepares students for their future engineering career (Sulzbach, 2007).

In this paper I will explore the University of Virginia 2024 concrete Canoe capstone as a case study in the expensive benefits of design clubs and competitions in engineering education. I believe we can better understand the broader impacts of experiential learning and advocate for its increased integration into the engineering curriculum.

Case Context

The concrete canoe was developed by Clyde Kesler, a professor at the University of Illinois, publishing the results of his concrete canoe experiment and encouraging other programs to build their own. The intent of the project was to provide young engineers with a unique design challenge and to provide a more engaging educational experience. The following year Purdue University developed their own design and the two schools decided to race their canoes to further engage and challenge their students. Soon professional engineering firms and engineering organizations began financially supporting and promoting the competition. A network begins to grow from the competition and the actors in that network begin shaping the ideas and values of the concrete canoe technology to reflect their own ideas and values.

Students are asked to engage with a lot of technical aspects when designing their canoe which can be broken down into three major sections. The first is the mix design of the concrete itself and characterizing the effect additives, aggregate, and differing amounts of cementitious material have on concrete (Leczovics, 2013). This includes researching new concrete mixes made out of recycled materials, conducting tension and compression tests, and sourcing unique materials that can provide advantages during construction. Next is the hull design which asks students to think critically about what forces will affect the canoe and how best to manage these forces through creative designs. This includes the use of modeling software (Paradis, 2007) to test the buoyant and hydrodynamic forces acting on the canoe while it moves to ensure a stable yet functional hull. Finally, construction engineering goes into the design of a mold that can properly support the weight of the concrete as it cures and delivers on the design, while keeping the project on time and on-budget. This includes using scheduling software, price tracking, and detailed design documentation to allow for a more thought-out building plan. This culminates in a complete technical report and oral presentation that explains the process of building the canoe and the technical skills these students learned along the way. Of course, the project is capped off with a float test and race which is the final event for the canoe and proves that, in fact, it floats.

The independence that these students have cannot be understated as they are expected to execute each of these tasks with only minimal help from an advisor. A key concept in the spirit of concrete-canoe is the importance of creativity, education, and teamwork. While many of the students who are asked to do these things have little to no experience, the time spent as a team researching, learning, testing, and failing cannot be replaced with a lecture. They aren't just tasked with building the canoe but learning to work with teammates, consultants, and professional companies when sourcing materials. These are important steps in engineering education and allow these students to challenge their ideas of what engineering looks like in the real world.

Actor Network Theory & Concrete Canoe

The Concrete Canoe Competition is well suited to be analyzed through the lens of Actor Network Theory (ANT), as its evolution and development have been deeply influenced by the engineers, students, and society that it's a part of. Actor Network Theory examines the social phenomena that is generated by human and non-human actors interacting within a network. Through ANT, technologies are not viewed as simply passive components but rather as relative actors that shape and are shaped by the network. ANT describes the process of enrolling other actors into the network by aligning interest, capabilities, and resources as "translation" and focuses on how the actors within a network are constantly shaping the goal of the network.

If we take for example the bicycle, we can identify the factors that make up that network such as cyclists, manufacturers, and engineers, as well as the non-human actors such as wheel types, gears, and frame material. The bicycle is an actor in the network connecting manufacturers to roads, to traffic regulation, and these actors interact dynamically shaping the bike to meet different needs.

In the context of Concrete Canoe, students engage with the competition and become actors in the network designing and building their canoes with a different set of resources, experiences, and goals expressed through their work. These values may take the form of students choosing to deliver a project that focuses on budget and performance or choosing to focus on sustainability and innovation. Through these interactions, they take part in shaping the network and values that make up the Concrete Canoe Competition. The competition's expansion to other universities broadened the network, leading to professional engineering organizations contributing resources, expertise, and support, thus reshaping its trajectory. Goals such as sustainability, innovation, reusability, and waste management can be introduced into the system through the form of judging each canoe. As more human actors interact with the system they learn about these goals and develop a more concrete understanding of what this technology can teach them. These goals shape the actors, and, in the future, those same actors may continue to interact with the network and reshape it once again.

When looking at the non-human actors we try to identify various technologies, tools, and artifacts that mediate the different human actors. We can see elements such as the concrete itself playing a central role in the competition as a major building component. Several human actors will study the composition of concrete and the material science that come with this heterogenous mixture to better understand how to design and construct things using it. We can also look at the technological innovations such as design modeling software, testing equipment, and simulation tools. These technologies allow students to analyze and optimize their ideas into more defined goals and actionable steps that are translated into physical prototypes. We can also look at the mold and reinforcement material as well as the coating and shaping tools that are used in the construction process. These components are key ideas that mediate how human actors can take their desired designs and specifications and actually bring them into the world. By recognizing the diverse set of non-human actors, ANT highlights the interconnectedness of the two groups and helps students translate experiences into true knowledge to meet their engineering challenges.

By applying the concepts of Translation from ANT, we can gain insights on how different actors mobilize resources, negotiate meanings, and exact change within the Concrete Canoe Competition. Translation takes place when students test different concrete mixtures, reinforcing materials, construction techniques, and optimize the performance of their canoes. Through these trials and errors, they translate abstract ideas and develop concrete strategies to meet the competition success criteria. We can also see mobilization in the mobilization of interdisciplinary collaborators such as students of different backgrounds, faulty advisors, and experts in the manufacturing field. By taking the shared knowledge of the project group and the specialized knowledge of experts within their faculty as well as material vendors, they are able to enhance the performance of their project results.

Overall analyzing the Concrete Canoe Competition through the lens of the Actor Network Theory framework gives us valuable insights in the dynamics that can be found between the human and non-human actors within the network. By choosing to focus on the agency of the different actors and the complex interactions that shape technological development, we can better understand the competition’s role in engineering education. ANT provides us with a more comprehensive understanding of the implications of the network and the intricate dynamics that the Concrete Canoe Competition offers for the large practice of engineering and education.

Research Question and Methods

The value of the design competition and key skills gained from participating in them seem to point out the flaws and gaps in engineering education. This leads me to ask a logical question: How can we incorporate the values, skills, and experiences from design competitions to improve engineering education as a whole?

To investigate this question, I analyzed responses to questionnaires that were sent to different concrete canoe clubs and professional engineering organizations assisting with this year's competition. The questionnaires were composed of free response questions and were intended to give participants an opportunity to reflect and share their experiences. I also conducted an in-person interview with Professor Lynn Mendeltort from the University of Virginia Center for Teaching Excellence to discuss different educational theories. I was most interested in the unique challenges with developing a curriculum for engineering education.

The questionnaire has specific sections of questions for different types of participants based on how they would view and interact with the network. This allowed me to better map the relationship between different actors that interact and shape the network. The first type was the "Competitor" which refers to students who are actively participating in the Concrete Canoe Competition this year. Next was the "Advisor" which refers to university staff that serve as the advising official to the club and professional mentor. The final participant type I had was the "ASCE Affiliated Engineer" which refers to professional engineers that volunteer and support the competition as a member of the American Society of Civil Engineers. The ASCE is the largest supporter of the competition and currently serves as the administrative body regulating the competition. Each of these types represents a unique perspective on the competition and provides valuable insight into the network. I received 12 questionnaire responses, and the below results are constructed using those responses.

After compiling the questionnaire and in person interviews, I analyzed the different responses using Actor Network Theory. I looked for general consensus among actor groups to map the different relationships between the actors and the network. I then looked for common concerns and common goals of the network to understand what key activities were seen as important by the network. By understanding what it is these design competitions do differently, we can generate more tangible goals that engineering education should work towards. I would like to identify and build upon already existing programs using the values and ideas gathered from understanding design competitions.

Results

The values that were most attributed to the Concrete Canoe Competition as an educational experience were interdisciplinary, technically challenging, realistic, and project focused. By analyzing the network using Actor Network Theory I was able to synthesis these four as the major goals of the network. These aspects should be used as the guiding principles in how to improve engineering education moving forward.

The majority of the "Competitor" participants stated their initial motivations to participate came from their curiosity and excitement to understand the physical properties of concrete. However, as they engaged with the competition their motivations shifted and began to center around the independence of the competition and the satisfaction of understanding industry practices, standards, and engineering principles. The concrete canoe then became a tool for them to experience their own personal design philosophies. At the University of Virginia sustainability became a major focus of the team and they prepared their canoe using low carbon cement and using a reuseable wooden mold. This design approach was praised by the judges at the 2024 Concrete Canoe Competition. Many of the “Competitor” participants noted that this experience allowed them to understand the intrinsic value of working on team based technically challenging projects. This shift from the desire to build a concrete canoe into a desire to demonstrate sustainability showcases how the network translates between different actors in the network.

The “Advisor” participant stated they viewed the competition’s main goal as helping students to learn skills outside of civil engineering such as material science, finance, architectural modeling, and project management. They felt young engineers must learn to be creative, resourceful, adaptive, and strengthen their love of learning as these skills were essential in engineering. The adviser stated they felt their role was to provide progress deadlines, identify future issues, and help consult on engineering solutions as providing a realistic engineering experience would help boost their professional portfolio. For the “Advisor” the competition's goals were translated from building a concrete canoe towards stewarding his profession and building the engineers of the future. This seems to fall in line with the original intent of the competition but shows that the mobilization to achieve those goals has shifted from direct teaching to indirect teaching.

The “ASCE Affiliated Engineer” viewed the goals of the competition as an opportunity to help young engineers find work after university and expand their professional network. They noted the long history of the competition draws the attention of dozens of engineering companies looking to hire bright young engineers. They felt the concrete canoe was simply a complex tool that allowed students to highlight their communication and leadership skills and improve their professional portfolio. When asked they noted that creativity, resilience, teamwork, willingness to step out of their comfort zone, and long-term thinking were all skills they look for in engineers they want to higher. As a result, many of the key deliverables for the competition revolve around challenging and showcasing these skills. This translation to concepts of professional development helps to illustrate how each actor can view the goals of the network differently and develop the technology to meet these goals.

My in-person interview with Professor Lynn Mandeltrot the Assistant Director of Engineering Education Initiatives at the University of Virginia revolved mostly around educational motivations. We discussed intrinsic motivations which is the idea of doing an activity for its inherent satisfaction rather than its consequences. She then explained extrinsic motivation which describes the motivation to do something to earn a reward or avoid punishment. She explained that education generally wants to foster intrinsic motivation in students to learn independent of the classroom environment. To achieve that goal, it's understood that students need a base level of competency in a subject, autonomy to learn at their own pace, and they must feel empowered to use that knowledge. We agreed that the Concrete Canoe Competition provides many of the necessary factors to develop extrinsic motivations.

Discussion

A common concern with engineering scholars is that globalization, the integration of artificial intelligence, and a focus on sustainability will change how we find engineering solutions in the future (Adams & Felder, 2008 pp. 237). Currently there is a growing concern that engineering education in the US must train future engineers to be adaptable and resilient to changes in the engineering landscape (Rotman et. Al, 2016 pp. 25858). Scholars also agree that nontraditional education experiences encourage multidisciplinary thinking and cultivate a lifelong desire to learn (Sulzbach & Candace, 2007 pp.12). I believe the Concrete Canoe Competition represents one of these nontraditional opportunities executes on the goal of training new engineers to be more adaptive and think more multidisciplinary.

My research was heavily limited by my timeline to complete the research, limitation on the length of my questionnaire, and the access to certain participant types. Unfortunately, I was unable send my questionnaire out until midway through my semester which gave the participants very little time to respond. I believe the short timeline to respond, and the stress of everyday student life discouraged many of my participants. The questionnaire itself was composed of only 11 questions, this was done to make it more accessible and encourage participation. However, I believe this was too short and didn't engage participants with enough varied questions or question types. Initially, I wanted to speak to an engineering educational administrator and try to understand their perspective, but I didn't receive any responses and lacked that data point from the network. Gathering more data on the values of participants would help me refine the exact values participants associate with the competition and specific activities that they feel are most beneficial. I believe more data would also help me identify the most effective way to apply the values and where they should be applied to during engineering education.

To improve my research, I would have sent the surveys much sooner to provide more time for additional participants to respond. I would have also given the participants the option to conduct a follow-up in-person interview where I could allow them to expand on their responses. I would make sure to reach out to engineering administration with a personal email that addresses them specifically as well as visit them during their open office hours if available. I also think varying the question type would have been an improvement since I feel the openness of the questions may have left some participants unsure of how much detail was needed. I would also expand the length of the survey to 15 – 20 questions and make a majority optional response in order to get a better understanding of what different participants feel is important to answer. Additionally, for the in-person interviews I would send a follow-up questionnaire asking for feedback and look to improve the quality of my interviews.

When looking at the current engineering education curriculum Professor Mandeltrot explained to me that the University of Virginia currently attempts to give students an educational experience like the Concrete Canoe Competition through the capstone project. The capstone project is a project based intellectual experience that allows students to demonstrate their research, analytical, and writing skills to prospective employers or graduate schools. This usually involves a team of students within the same major being assigned a real-world project by either a professional agency or the university that attempts to mimic some type of professional work. Some key characteristics of this project include developing a project schedule, project budget, progress reports, key deliverables, and a presentation on their work. At the University of Virginia this is a required course in order to graduate and typically takes place during their final year. While I believe the capstone is a valuable experience, we can enhance this learning experience by looking at the values we identified during my research.

An area I feel the capstone project can improve is providing more multidisciplinary learning opportunities. In the current capstone format engineering students are only allowed to work on projects that fall into their discipline without special permission. While this makes practical sense, I feel this removes an opportunity for students to practice their individual skills in a more complex environment. The concrete canoe models these interdisciplinary projects as concrete requires knowledge on material science, hydrodynamic analysis is needed in hull design, and cost and schedule analysis are needed in project management. One example of this translation would be allowing construction engineering students to bring the management and cost estimation skills they've learned in class to an architecture capstone and provide practical consultation. Another example is an environmental engineer working to design a natural system in support of an environmental science capstone. This role as the civil engineering lead on these projects challenges students to be creative, adaptive, and step out of their comfort zone, like the concrete canoe competition does. The capstone project already meets the values of being technically challenging, realistic, project focused, and with the integration of the interdisciplinary value it can take one step further as an education experience.

Conclusion

By looking at Concrete Canoe Competition as an educational tool we can find the vital role design competitions have in bridging the gap between theories and practice. Non-traditional learning opportunities like the competition offer students a chance to apply the theoretical principles they learn in class to real work challenges and fosters creativity, teamwork, and problem solving. Actor Network Theory provides a lens to understand the unique interactions between human and non-human actors within the system. By analyzing the goals and interactions between the actors in the network we can synthesis a key set of values that we can map onto current engineering curriculum. These values are project focused learning, working under realistic expectations, engaging with technically challenging opportunities, and a focus on interdisciplinary collaboration. Moving forward I believe integrating these values is imperative to enhancing engineering educational curriculum and preparing students for the complex engineering problem we will face in the future. Engineers have a responsibility to serve humanity and make the best of the earth's precious wealth and so it's our responsibility to prepare the next generation to uphold that great responsibility.

Resources

Adams, R. S., & Felder, R. M. (2008). Reframing Professional Development: A Systems Approach to Preparing Engineering Educators to Educate Tomorrow's Engineers. *Journal of Engineering Education*, *97*(3), 239–240. https://doi.org/10.1002/j.2168-9830.2008.tb00975.x

Arciszewski, T., & Harrison, C. (2010). Successful civil engineering education. *Journal of professional issues in engineering education and practice*, *136*(1), 1-8.

Bharath, M., Saravanan, J., Kumar Sha, A., Ram Ghimire, B., Bhagat, K., Sherstha, L., Ghimire, P., Kasaudhan, R., Sha, S., & Madhu, S. (2022). Novel sandwich structure approach to develop lightweight concrete canoe. *Materials Today: Proceedings*, *65*, 1779–1784. https://doi.org/10.1016/j.matpr.2022.04.801

Bix, A. S. (2019). Mastering the hard stuff: The history of college concrete-canoe races and the growth of engineering competition culture. *Engineering Studies*, *11*(2), 109–134. https://doi.org/10.1080/19378629.2019.1647217

Carnivale, M. (2001). Design-build of a concrete canoe- from start to finish line. *Concrete international*, *23*(11), 41-44.

Crawley, E., Malmqvist, J., Ostlund, S., Brodeur, D., & Edstrom, K. (2007). Rethinking engineering education. *The CDIO approach*, *302*(2), 60-62.

Downey, G. L., Lucena, J. C., Moskal, B. M., Parkhurst, R., Bigley, T., Hays, C., Jesiek, B. K., Kelly, L., Miller, J., Ruff, S., Lehr, J. L., & Nichols-Belo, A. (2006). The Globally Competent Engineer: Working Effectively with People Who Define Problems Differently.

Journal of Engineering Education, *95*(2), 107–122. https://doi.org/10.1002/j.2168-9830.2006.tb00883.x

Downey, G., & Lucena, J. U. A. N. (2003). When students resist: Ethnography of a senior design experience in engineering education. *International journal of engineering education*, *19*(1), 168-176.Jipa, A., Bernhard, M., Ruffray, N., Wangler, T., Flatt, R., & Dillenburger, B. (2019). Formwork fabrication freedom for a concrete canoe. *Gestão & Tecnologia de Projetos*, *14*(1), 25–44. https://doi.org/10.11606/gtp.v14i1.148264

Houston, B. (2005, June). Incorporating concrete canoe & steel bridge planning into a construction management course. In *2005 Annual Conference* (pp. 10-740).

Latour, B. (1992). Where are the missing masses? The sociology of a few mundane artifacts. Shaping technology/building society: Studies in sociotechnical change, 1, 225-258.

Leczovics, P., & Sugár, V. (2013). Concrete canoe: A complex concrete technology. *YBL Journal of Built Environment*, *1*(2), 43–55. https://doi.org/10.2478/jbe-2013-0011

Paradis, F., & Gendron, G. (2007). Structural modeling and testing of a concrete canoe. *Ocean Engineering*, *34*(1), 206–217. https://doi.org/10.1016/j.oceaneng.2006.01.006

Pradeep, S., Deepak, P., & Dheepak, S. (2020, August). Rice husk ash based cementitious material for concrete canoe. In *IOP Conference Series: Materials Science and Engineering* (Vol. 912, No. 6, p. 062004). IOP Publishing.

Ribeiro, L. R. D. C., & Mizukami, M. D. G. N. (2005). Student assessment of a problem-based learning experiment in civil engineering education. *Journal of Professional Issues in Engineering Education and Practice*, *131*(1), 13-18.

Rottmann, C., Sacks, R., Klassen, M., & Reeve, D. (2016). Sports, arts and concrete canoes: Engineers learning to lead outside the formal curriculum. *2016 ASEE Annual Conference & Exposition Proceedings*, 25858. https://doi.org/10.18260/p.25858

Sanjay Jayakumar, Abhishek Kurian, Febin T Zachariah, Nivin Philip, & SAINTGITS College Of Engineering. (2020). Construction of Concrete Canoe using Light Weight Aggregates. *International Journal of Engineering Research And*, *V9*(04), IJERTV9IS040461. https://doi.org/10.17577/IJERTV9IS040461

Schmitt, S. B. (2006). The Vanderbilt Concrete Canoe Design Project: The Little Engine that Canoed. *Vanderbilt Undergraduate Research Journal*, *2*.

Shuman, L. J., Atman, C. J., Eschenbach, E. A., Evans, D., Felder, R. M., Imbrie, P. K., ... & Yokomoto, C. F. (2002, November). The future of engineering education. In *32nd Annual Frontiers in Education* (Vol. 1, pp. T4A-T4A). IEEE.

Sulzbach, C. (2007). Enhancing engineering education ? Concrete canoe competition. *2007 Annual Conference & Exposition Proceedings*, 12.665.1-12.665.16. https://doi.org/10.18260/1-2--2280

Thanon Dawood, Dr. E. (2015). Experimental study of lightweight concrete used for the production of canoe. *AL-Rafdain Engineering Journal (AREJ)*, *23*(2), 187–197. https://doi.org/10.33899/rengj.2015.101085