Workforce Development Through Experiential Learning and Collaboration between Industry, Government, and Universities to Solve Environmental Challenges

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Abstract

The WERC Environmental Design Contest empowers engineering students with needed workforce skills as they participate in experiential learning that includes innovative design work, presentations, and bench-scale demonstrations of working prototypes. Collaboration with industry and government partners gives students the opportunity to solve real-world environmental challenges, be mentored by engineering professionals, and have the potential to see their designs further developed and implemented by the contest sponsors.

Data collected at the design contest indicates that students improved in seven workforce-development competencies, suggesting that students who participate in long-term, hands-on globally responsible projects develop valuable technical and professional skills that prepare them for a dynamic workforce. Of particular note is the high percentage of participation by females and first-generation college students in the design contest, indicating that design contests can serve to increase confidence and more fully develop the needed technical and professional skill sets for these underrepresented groups.

Although experiential learning has historically been reserved for the senior year and more recently incorporated into many Freshman curricula, data from the WERC Environmental Design Contest indicate the value of filling the gap between the Freshman and Senior years with an engineering design contest as an out-of-class instructional vehicle.

Introduction

Workforce development in the undergraduate engineering curriculum serves two primary constituents: students and their prospective employers. The students seek the technical and professional skills they need to remain successful through their careers. Employers, including government agencies, non-profits, and industry, depend on talented engineers who are adaptable and able to sustainably support the goals of their organization and, ideally, society as a whole[1]. Pusca et al. point out that the primary objective of engineering education is to provide an agile system that reduces the gap between engineering graduates' attributes and the expectations of employers[2].

To address the needs of these two constituents, colleges and universities are recognizing the benefits of project-based learning (PBL) and hands-on engineering design work in the engineering curriculum. Pusca et al. caution that hands-on design projects must add value to a student's education, producing long-term skills and knowledge that can be applied to new problems[2]. Under a well-designed PBL program, students can experience improvement in their motivation and self-efficacy[3, 4]. Student motivation is enhanced when students feel that they have made a positive impact on society[5]. Further motivation comes from projects based on real-world needs of customers, as they teach students to communicate with and meet the needs of a client [6,7]. Wu et al. observed that project- and team-based courses have a particularly positive effect on the academic achievements of female students[8].

Historically, design projects have been reserved for senior capstone design courses. In some institutions, these are pen-and-paper studies, and in others they are hands-on design projects. More recently, freshman PBL (often referred to as "cornerstone" courses) has been added to many undergraduate engineering curricula to motivate young engineering students while teaching the basics of engineering design and entrepreneurship [6, 9, 10, 11, 12].

For most institutions, this leaves a gap between the Freshman and Senior years with few hands-on design experiences available for students as a part of the curriculum. To fill this gap, out-of-class activities, such as design contests, can be a valuable supplement to the undergraduate curriculum.

Polmear et al. observed that out-of-class activities can help students develop attributes that are not sufficiently covered in the curriculum[13]. They reported that students who engaged in out-of-class activities more strongly believed themselves to have achieved the attributes of *The Engineer of 2020* (outlined in the National Academy of Engineering's list of 10 desirable attributes for engineers[14]) than did their peers who were not involved in out-of-class activities. These attributes include analytical skills, ingenuity, creativity, communication, business and management skills, leadership, ethical standards, professionalism, resilience and flexibility, and lifelong learning. Most notable in this research study is that females and first-generation college students credited their participation in design competition teams as being most effective in helping them develop *The Engineer of 2020* attributes[13].

Numerous studies have outlined the advantages of faculty mentoring, with added contributions when the faculty is not the primary instructor[15,16]. Also of great value to workforce development is mentoring by engineers from industry who bring a wealth of practical experience and the workforce perspective[17,18,19].

Overview of Workforce Development through the WERC Environmental Design Contest

The WERC Environmental Design Contest implements all of the above approaches to engineering education in one project-based package that can be implemented in the sophomore through senior years. The contest provides hands-on design projects that are based on real-world needs, thereby providing the opportunity for students to make a positive impact on society and the environment while being mentored by their faculty advisors and collaborating with practicing engineers.

The design contest is modeled after the engineering Request for Proposals (RFP), with each event in the contest reflecting the process followed by an engineering firm as they answer an engineering RFP. To develop real-world challenges, WERC partners with industry and government agencies to develop tasks that address some of the major environmental concerns that the world faces today.

Each year, WERC offers a diverse set of design challenges. From these, student teams select one task to focus on. Each task is designed and sponsored by industry and/or government agencies to solve a real problem of concern. Sponsorship of a task is an investment in the future workforce, but also provides the sponsors with fresh and innovative perspectives that often serve as springboards for new avenues of research at the sponsoring organization. In recent contests, students have chosen among tasks such as (task sponsors in parentheses): PFAS Destruction (CDM Smith), Microplastics Quantification in Reservoirs (Dell Technology), Advanced DERMS Technologies (El Paso Electric Company), Rural Wastewater Treatment for Water Re-use (EPA), Long-term Water Storage (NASA), and Dust Removal for Space Suits (NASA). The tasks are open-ended, allowing for creativity, innovation, and team-directed designs.

At their home institution, a team selects a task, researches the topic, develops an initial design, builds a working bench-scale apparatus as proof-of-concept for their design, then tests (and repeatedly modifies and re-tests) their apparatus against the desired task outcomes. The team plans for scale-up, conducts a techno-economic analysis, develops a business plan, and addresses community involvement and government regulations.

Each team writes a 25-page report and prepares a conference-style poster that they bring to the event in Las Cruces, New Mexico, along with their working bench-scale apparatus. At the contest, faculty advisors step aside to allow the judges to work with the teams. The judges are practicing engineers that have many years of experience in the workforce. The judges are trained to treat the teams as colleagues as they discuss with the teams the practicalities of government regulations and the nuances of preparing a design for implementation. The students not only learn practical engineering and business skills from the judges, but they also develop the confidence to engage potential employers and launch their careers with confidence.

Workforce Development through Mentoring

A key component of the design contest is that the students are organized in teams, with a student serving as the Team Leader. The Team Leader is encouraged to assign each team member specific responsibilities. This develops valuable leadership skills among each team member and frees the faculty advisor to act as the team's consultant—to mentor, advise, and prepare the team to compete at the design contest.

Following the model of the RFP, the design contest ensures that teams are mentored by three separate sets of engineering professionals. First, at their home institution, faculty advisors are urged to serve as consultants to the team while allowing the team freedom to design their own solution to the task. Second, teams are mentored by a group of judges assigned by WERC. The teams first

interact with the judges when they submit an interim report (the 30% Project Review). Judges send feedback, but do not score the 30% Project Review. This early feedback helps the teams better understand their project-flow diagrams, scale-up considerations, and the practical implementation of their designs without fear of "losing points." Judges meet with the teams in person at the design contest, where they spend two days with the teams. These judging sessions are discussed in more detail below. Third, as is required of most design projects at an engineering firm, the teams are required to obtain three outside audits from professionals who are experts in each of three areas: Economics, Health & Safety, and Legal. These three areas are selected for the audits because teams tend to have less experience in these areas, and the feedback from auditors provide valuable instruction from a professional perspective. Mentoring from these three sets of engineering professionals provides a variety of workforce preparation for students that they do not ordinarily experience in the typical college classroom.

Judges, who are practicing or retired engineers serve as WERC's primary workforce development mentors. At the design contest, groups of at least five judges mentor each team from start to finish—including scoring the technical report, the oral presentation, the poster presentation, and the bench-scale demonstration. Judges are instructed to discuss the team's designs from the standpoint of a colleague, encouraging teams to propose potential improvements to their designs and proposed plans for scale-up. This has proven to be an effective strategy, promoting the students' confidence in effectively communicating their ideas. It is noteworthy that student participants remark that the judges "treat us as colleagues, rather than making us feel judged"[20].

The workforce-development framework is illustrated in Figure 1. First, WERC has modeled the contest after the engineering RFP. This contributes to the students' understanding of how an engineering firm approaches a request for proposals from a potential client. Second, a team of professional engineers from industry and government agencies develops real-world environmental challenges. These tasks not only motivate students by providing problems that may be applicable in their careers, but they also enable students to make a contribution to the environmental knowledge base, since the sponsors that propose the tasks are seeking new perspectives in solving challenging problems. Third, teams benefit from two-way project reviews with the Team Leader and among team members. Fourth is the two-way communication between the faculty advisor (the "consultant") and the team, helping to guide the team toward sound engineering judgement while allowing them the freedom to design their project independently. Fifth are the professional engineers from outside the institution who mentor the teams either through audits of the technical report or through the 30% Project Review and the onsite contest judging.

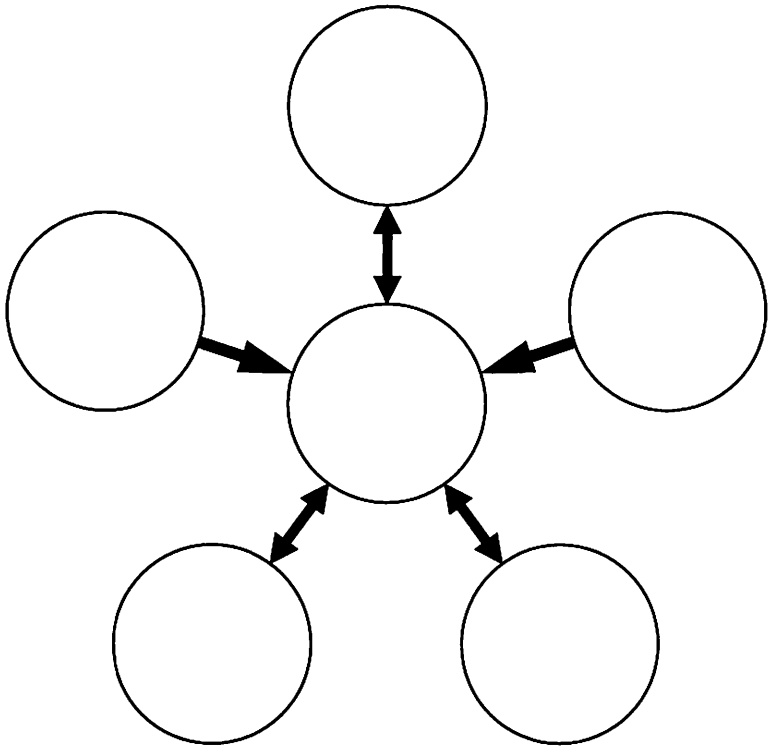

Figure 1. Teams are guided by the engineering RFP and professionally-designed tasks (dark purple). Two-way communication develops confidence in the students (double arrows) as Student Team Leaders regularly guide the teams and professional engineers and faculty advisors provide ongoing mentorship and collaboration (teal circles) resulting in a student-centered workforce development experience.

Student Assessment of Engineering Skill Development

At the 2022 WERC Environmental Design Contest, 112 students competed in the contest. Of these, 50% identified as female and 50% identified as male. The percentage of females participating in the design contest is significant, since females were reported by MDPI to comprise only 17% of all engineering majors in 2021[21]. This data alone supports findings of researchers that females respond positively to design competitions and project- and team-based curricula[8,11].

34 students participated in an exit survey that evaluated their perceptions of the effects of the WERC Environmental Design Contest on their engineering skills. Of these students, 57% of the respondents identified as female and 43% identified as male. 29% were classified as Freshmen, Sophomores, or Juniors, 20% identified as first-generation college students, and 12% identified as Hispanic or Latino. As points of reference, in 2022, Cornell University reported that 10% of undergraduate engineering students are first-generation[22], and in 2016 the National Science Foundation reported that 10.4% of engineering students in the U.S. were Hispanic or Latino[23]. The results of WERC's survey are shown in Figure 2.

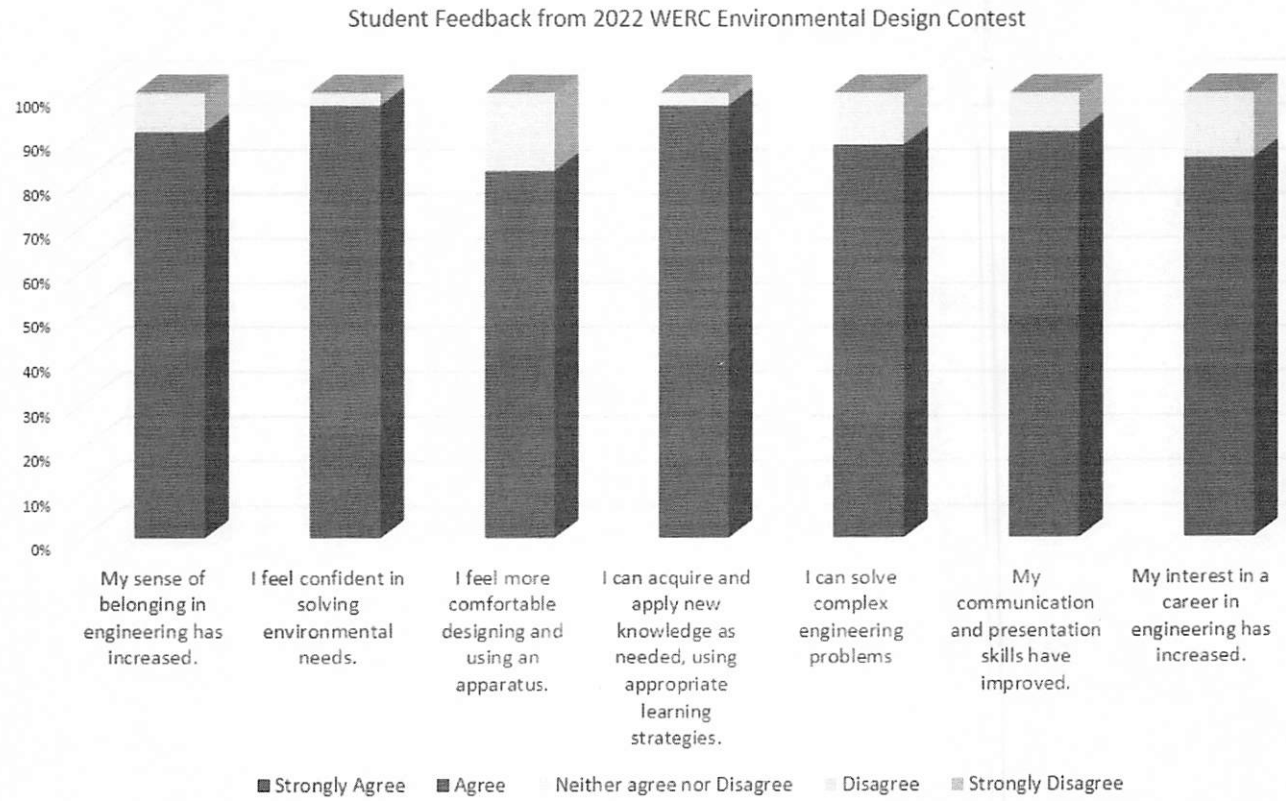

Figure 2. Results of the student exit survey from the 2022 WERC Environmental Design Contest reflecting student's assessment of their engineering confidence and skills. Over 82% of students agreed or strongly agreed with the statements. Zero students responded "Disagree" or "Strongly Disagree."

The data illustrated in Figure 2 shows that for all survey questions, at least 82% (in most cases over 90%) of the respondents agreed or strongly agreed with the statements (see Table 1). It is significant that 91% of the respondents agreed or strongly agreed that the contest increased their sense of belonging in engineering and improved their communication and presentation skills, professional skills that are highly valued by employers.

Leading the student perceptions with 97% of the respondents agreeing or strongly agreeing were the statements "I feel confident in solving environmental needs" and "I can acquire and apply new knowledge as needed, using appropriate learning strategies." The latter statement, reflecting the students' ability to acquire and apply new knowledge and use appropriate learning strategies, represents the epitome of our goals in workforce development—to develop an agile workforce that can adapt to changing expectations of organizations and society.

Table 1 outlines the number of students who agreed or strongly agreed with each of the statements listed in Figure 2. It is noteworthy that a small number of students responded neutrally and zero students responded "disagree" or "strongly disagree."

Table 1. Percentage of Students responding "Agree" or "Strongly Agree" to survey statements.

Survey Statement	**Percent of Students responding "Agree" or "Strongly Agree"**
My sense of belonging in engineering has increased.	91%
I feel confident in solving environmental needs.	97%
I feel more comfortable designing and using an apparatus.	82%
I can acquire and apply new knowledge as needed, using appropriate learning strategies.	97%
I can solve complex engineering problems.	88%
My communication and presentation skills have improved.	91%
My interest in a career in engineering has increased.	85%

Summary and Conclusions

According to the results of the 2022 exit survey, the WERC Environmental Design Contest improved seven workforce development competencies, including students' sense of belonging in engineering, confidence in solving environmental needs, comfort level in designing and using an apparatus, confidence in ability to acquire and apply new knowledge, ability to solve complex engineering problems, communication and presentation skills, and their interest in a career in engineering.

With 29% of respondents classified as Freshmen, Sophomores, or Juniors, the results indicate the value of student participation in out-of-class design contests, particularly in the "gap" years between the Freshman cornerstone courses and the Senior capstone courses.

The overwhelmingly strong participation in the contest by women and first-generation students, coupled with the positive outcomes experienced at the WERC Environmental Design Contest, implies that such programs may be instrumental in increasing the success rate, recruitment and promotion of these traditionally underrepresented groups.

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