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Introduction

Over the past decade, participation in national and international design competitions has grown significantly among mechanical engineering students at Ohio Northern University, a private, comprehensive, residential institution in the Midwest. At the same time, these competitions have come to play an important role in achieving the educational objectives of the department. This paper will review several such competitions, evaluate the degree to which they contribute to the educational experience of the students, and discuss some of the advantages and limitations of these activities.

While traditional lectures, tutorials, and structured assignments are still essential to providing the foundation for an understanding of engineering science and the skills required to solve math- and physics-based problems, many of the abilities required by accrediting bodies and potential employers are difficult to achieve using these methods. Senior capstone projects and design problems related to specific courses have become common tools for teaching skills such as working in teams, solving open-ended problems, and communicating both technical and non-technical information. While these methods have met with significant success, continued expansion of curricular-based approaches is constrained by competition for limited class time with the varied other demands on the undergraduate engineering curriculum. In addition, "open-ended" projects often require significantly higher demands on faculty than traditional structured lectures and assignments.

External design competitions, either independent or sponsored by a professional society or other organization, provide an additional approach to augment the engineering education of undergraduates. This paper will consider four such competitions. The SAE Baja and Aero Design competitions, sponsored by the Society of Automotive Engineers, are well-established international competitions in which students from Ohio Northern University (ONU) have participated for a number of years. The Human-Powered Vehicle Competition, organized by the American Society of Mechanical Engineers, is also an international competition, but involvement by ONU students only began during the 2009/10 academic year. The first Robotic Football Competition, organized by the University of Notre Dame and funded by private sponsors, took place in the spring of 2009. Students from ONU observed the game in 2010 and first competed in 2011. Each of these competitions offers valuable experience on how student involvement can enhance undergraduate engineering education, and provides insight into some common advantages and disadvantages of such involvement.

Several authors write of the many-faceted benefit of competition projects. Sulzbach writes that that the Concrete Canoe competition[1] enhances the educational experience by producing an atmosphere of school pride among team members, fostering creativity, and encouraging peer-to-peer learning as students pass along the cumulative team knowledge and experience. Competitions such as these put students in many real world situations which are "typically not available to a student in the standard … engineering curriculum." [2]

Pinski et al. describe how "learning is enhanced during senior engineering design projects when marketplace constraints such as competition, limited resources, and administration are added to the assignment." [3] Competition benefits both learning and motivation. Learning benefits come as the constraints force students to focus on simple, inexpensive, and robust designs. Motivational benefits include the pride students take in their competitive product and the absolute measure of success waiting at the end of the project. Students are motivated by one another to go beyond the typical capstone goal of merely completing a prototype which fulfills the minimum design requirements.

Wankat surveyed hundreds of advisors for teams which had placed 1st through 3rd in undergraduate student competitions.[4] He also found "significant agreement that students learn many practical aspects of engineering, both technical and non-technical, that they probably do not learn elsewhere." One survey respondent stated that "Just working in [the competition] environment is often what it takes for schooling to finally make sense to students." Another noted that "Students that have competed consider it one of the highlights of their education. Even those that did not win value the experience."

Baja SAE

The off-road vehicle competition known as Baja SAE, first held in 1976 with 10 teams and 90 students[5], now involves hundreds of teams and multiple competitions worldwide. In 2011 the North American series alone included three sanctioned regional races in which over 2200 students participated. These competitions "simulate real-world engineering design projects and their related challenges. Engineering students are tasked to design and build an off-road vehicle that will survive the severe punishment of rough terrain and sometimes even water." [6]

Each team builds a vehicle from scratch, powered by a common stock gasoline engine. Though there is a large degree of design freedom in constructing the car, students must satisfy a rigid and extensive list of dimensional and safety requirements before they are able to compete. Students drive their own car in the competition, the results of which are based on several different driving events and scores from written reports and oral presentations.

SAE states that the object of the competition is “to provide SAE student members with a challenging project that involves the planning and manufacturing tasks found when introducing a new product to the consumer industrial market. Teams compete against one another to have their design accepted for manufacture by a fictitious firm. Students must function as a team to not only design, build, test, promote, and race a vehicle within the limits of the rules, but also to generate financial support for their project and manage their educational priorities.” [6]

Figure 1: Ohio Northern University Baja team

The major components of the competition are design, manufacturing, project management, and presentation. The design tasks are quite extensive, encompassing many aspects of mechanical design with applications to automotive engineering. A variety of manufacturing techniques are employed, and many more considered but not chosen due to cost, complexity, reliability, and so on. Project management is also crucial, for the design and construction of a competitive Baja car consumes hundreds of student hours, mostly during the academic year. Students develop valuable skills in planning, budget generation and tracking, purchasing, and team motivation. Finally, the project presentation takes several forms, including written and oral design reports, a cost report, and sometimes a marketing presentation.

Ohio Northern University first fielded a Baja team in 1996 and has been continuously involved since then. The ONU involvement began as a senior capstone project, but changed to an all-volunteer team in 2004. (This transition, incidentally, proved exceptionally beneficial. The capstone teams invariably performed poorly in the competitions, but the volunteer squads have demonstrated continuous improvement and marked success, with three top-ten finishes in 2011. Details of the transition and the advantages of volunteer teams are documented in an SAE publication.[7])

SAE Aero Design

The SAE Aero Design competition is not quite as old as Baja, having started in 1986. It, too, enjoys broad popularity, attracting 132 teams and approximately 800 students in the 2011 North American competitions.[8] As with the Baja competition, this event “has been designed to provide exposure to the kinds of situations that engineers face in their real-life work environment." [9] Three classes of competition are featured – Regular, Advanced, and Micro – to enable teams with a range of skill levels and interests to participate on more equal footing.

For this event, students must design and construct a model aircraft to "optimally meet mission requirements while still conforming to the configuration limitations." [9] Standard components such as wheels, motors, and landing gear may be purchased, but students must do all fabrication of the wings, fuselage, and tail assembly.

To produce a competitive aircraft, students must evaluate competing design options and make compromises to achieve the best solution. The submitted design must include an analysis of the vehicle flight dynamics and predictions of the expected performance. But the experience is not only about design; the competition also emphasizes written and oral communication by requiring a design report and presentation which contribute significantly to the team's overall score. In addition, in order to obtain university funding the ONU team must submit a detailed components list and budget to the Dean of Engineering, and they must maintain detailed accounting records throughout the project.

Figure 2: ONU teams for SAE Aero Design (left) and AIAA Design/Build/Fly (right)

The ONU chapter of the American Institute of Aeronautics and Astronautics (AIAA) has also occasionally participated in a similar aircraft-building competition, the AIAA-sponsored Design/Build/Fly. In contrast to the SAE event, this competition's design requirements and performance objectives substantially change from year to year to "encourage innovation and maintain a fresh design challenge for each new year's participants." [10]

ONU has alternated between SAE Aero Design and AIAA Design/Build/Fly since 1997, though they have not competed every year. Some years ONU has fielded two teams, and some efforts have been capstone projects while others were solely volunteer projects of the AIAA professional society chapter.

ASME Human-Powered Vehicle Challenge

The American Society of Mechanical Engineers (ASME) supports a number of design competitions which tend to focus on sustainability- or humanitarian-oriented projects. One of these, the Human-Powered Vehicle Challenge, "provides an opportunity for students to demonstrate the application of sound engineering design principles in the development of sustainable and practical transportation alternatives." [11]

Students design, build, and race what are essentially recumbent bicycles, though often encased in an aerodynamic or protective shell. Vehicles compete based on design methodology, innovation, and safety, as well as speed and endurance.[12] As with the competitions already discussed, the mechanical design is supported by a written report and an oral presentation. During the presentation, students are required to demonstrate a significant innovative feature of their design.

Though the Human-Powered Vehicle Challenge has existed since at least 2002, Ohio Northern University's initial entry was in the 2009-10 season, when a group of seniors petitioned to enter this competition as a capstone project. When this first effort scored third overall in a field of eighteen teams, enough excitement was generated in the ASME chapter to continue the project as a volunteer effort in subsequent years.

Figure 3: 2010 ONU HPVC team

Robotic Football Competition

The Robotic Football Competition, organized by the University of Notre Dame and funded by private and corporate sponsors, has taken place each spring since 2009. Over the past three years, this competition has been the capstone project for all mechanical engineering undergrads at Notre Dame, split to form two teams. Each team designs and constructs a full array of robotic players, including linemen, receivers, a running back, and a quarterback. Each robot base is a roughly 2-foot square of polyethylene sheet, to which appropriate sensors, lights, and actuators are attached. All players are primarily remote controlled, though some advanced programming enables multiple actions through a single button press.

Figure 4: Scenes from Robotic Football competition.[13] At right, the passing robot is discussed.

Through this event, Notre Dame aims to "introduce a new intercollegiate competition that will be fun for all spectators and demonstrate the challenges and excitement of engineering."[14] One project organizer notes that the "participants will use the skills they acquired during the project during their careers … to develop, among other things, intelligent prostheses, biomedical devices, and electromechanical systems in general."[15]

Students from ONU observed the game in 2010 and were first invited to compete in 2011. Though the ONU capstone group did not field an entire team, an NFL-style combine and draft was held to blend these players with the Notre Dame teams. ONU was again invited to participate in 2012, this time to construct a full team of robotic players.

Though this smaller competition does not have the same central oral and written report requirements of those sponsored by the professional societies, the capstone course requirements for both universities ensures that these elements are not neglected.

Nature of Ohio Northern University Involvement

Ohio Northern University has been involved in these competitions for various amounts of time. Baja and Aero Design competition teams have been staples since the mid-1990s, whereas the Robotic Football and Human-Powered Vehicle Challenge (HPVC) teams are only two and three years old respectively.

Variety also exists in the team structures. Though Baja began as a capstone project, it has been a volunteer effort of the SAE professional society for the past seven years. The aircraft design teams (Aero Design or Design/Build/Fly) alternate between a capstone and volunteer-led structure (or both), driven year-to-year by levels of student interest. The Human-Powered

Vehicle Challenge also began at ONU with a capstone team, but continues as an ASME chapter volunteer project. The Robotic Football team has been a capstone project for each of its two years at ONU, though this year's smaller capstone group and larger workload has led them to solicit volunteer help for construction of the robots.

Likewise, the degree and nature of student engagement differs widely among these competition teams. The Baja team is dominated by two to five passionate and extremely dedicated students who devote 20+ hours per week to the project for most of the school year. Another three students contribute regularly, but to a lesser degree, and six to eight additional students periodically attend meetings and may occasionally help in the shop or travel to a race.

Participation in Baja tends to be an "all or nothing" affair. Though Baja leaders try to encourage students who would like to contribute but cannot match the others' ardent devotion, the less committed students often feel unwelcome among the brotherhood of zealots. On this veteran team pursuing excellence and continuous improvement, it is difficult for a new student to jump in and contribute meaningfully without some existing automotive or manufacturing experience.

While the aircraft design competitions require significant knowledge and skill from several team members, it appears to be easier for new students to provide meaningful contributions. Student leaders of the AIAA chapter report that about five students are dedicated to the project, though the time commitment is a more modest 4-8 hours per week during the ten-week design phase and 8-10 hours/wk for manufacturing through the subsequent ten weeks. Seven additional students give smaller regular contributions, and four more provide occasional help. Some time-consuming tasks, such as sanding, can be performed by a freshman who is curious about the project and willing to donate a few hours. The Aero Design team leader was asked to rate on a scale of 1 (easy) to 10 (hard) the difficulty for a novice to meaningfully contribute to the project. The leader answered 5, noting that "as we get later in the year it gets harder to get involved."

Three or four students are "very committed" to the HPVC project this year, according to team leaders. The leaders describe this level of commitment as 2 hours/wk for the first semester and 4-8 hours/wk for the second semester. Five more students participate regularly, though to a lesser degree, and another six students have helped out occasionally. When HPVC leaders were asked to rate the ease of meaningful contribution as described for the Aero Design project above, the response averaged 2.5. Both leaders added a comment that it would have been even easier had they been asked earlier in the year. "This is a very young, inexperienced team so newcomers would not be that far away from the more 'seasoned' ones."

Level of participation in the Robotic Football Competition, being a formal capstone project assigned to a certain group of students, is less a reflection of commitment. The hours devoted by capstone students can certainly indicate a degree of enthusiasm, but a minimum of three hours in the fall semester and six hours in the spring is expected of all capstone students. Though volunteers are now being recruited to assist this year's team in robot construction, it is too early to evaluate their usefulness.

Clearly these four projects define commitment quite differently, ranging from two to twenty hours per week. The variety of projects and their corresponding "barriers to entry" enables students with a wide range of time and interest to find a place where they can contribute.

Educational Impact

External engineering competitions support the Program Educational Objectives and Program Outcomes established by the Mechanical Engineering Department at ONU.[16] The former are listed in the appendix, while the latter closely align with the eleven ABET engineering accreditation criteria[17] (also in the appendix).

The tasks and requirements described for the Baja competition, for example, represent explicit fulfillment of five of the ABET criteria (a, c, e, g, k). The design competition additionally presents opportunities to fulfill four other criteria (b, d, f, i), such as an understanding of professional and ethical responsibility and an ability to function on multidisciplinary teams. Sirinterlikci and Kerzmann cite specific ways in which all eleven criteria were satisfied in their school's Baja experience.[18]

All four of the Program Educational Objectives are clearly supported by each of these external competitions. All involve application of mechanical engineering principles to develop or improve the competition product (off-road vehicle, aircraft, etc.). All require effective oral and written communication as well as good teamwork. Each project includes important safety criteria which could endanger life and health if ignored, helping students recognize an engineer's impact on society. And finally, all projects require knowledge not explicitly gained in the classroom, forcing students to practice the independent learning essential for continued professional development.

These competitions also boost student engagement. The projects necessitate self-directed and peer-directed learning and foster multi-year involvement. The multi-year experience provides the opportunity for students' natural growth from the novice learner, to peer trainer, to team or functional group leader.

This student engagement is a critical element in a positive college experience according to Pascarella and Terenzini.[19] These authors further note that the greatest impact on student learning and development occurs when academic and extracurricular involvements are "mutually reinforcing," which can certainly be said of these competition projects. (Of course only those projects not limited to capstone students can truly be characterized as extracurricular.)

External engineering competitions enrich students' professional preparation not only through their direct activities but also through their integration into the classroom. Most competitions require or encourage students to apply design and analysis tools they have learned in mechanics or manufacturing courses. But often there are also opportunities to use competition tasks to satisfy course requirements, and even to boost the engagement and learning of students who are not on the project team.

For instance, students are encouraged to use competition components for the course project in Finite Element Analysis (FEA). Figure 5 shows two student-generated stress analyses from 2010-11. The left figure displays the stress distribution in the proposed Baja steering linkage under an impact load; the right figure demonstrates a similar analysis for the Aero Design wing. The teams get the added benefit of being able to discuss these analyses in their competition design reports.

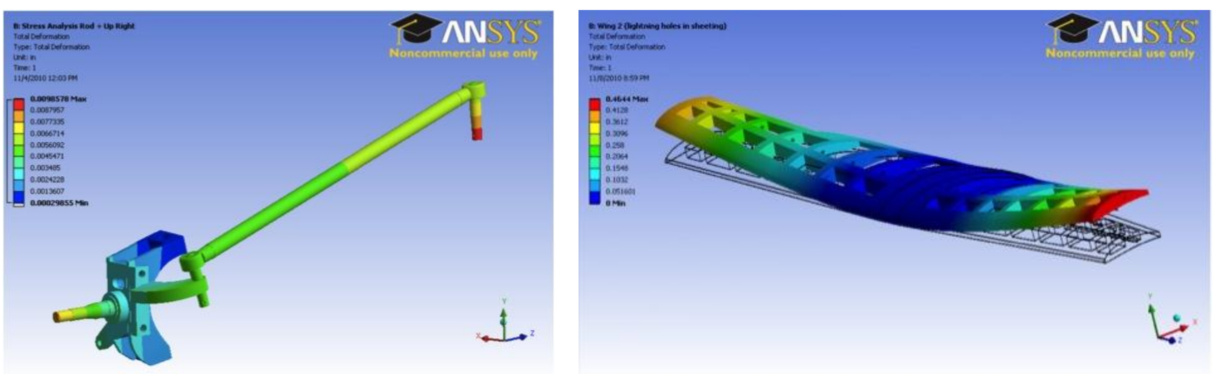

Figure 5: Finite element stress analysis of Baja steering linkage (left) and Aero Design wing (right)

Computational Fluid Dynamics (CFD) is another course in which students directly employ competition challenges in classroom work. Figure 6 exhibits flow analyses for the proposed Human-Powered Vehicle Challenge shell – which was subsequently redesigned as a result of this study – and for the Aero Design airframe. The HPVC study calculated the drag coefficient for the body, while the Aero Design students used their analysis to calculate lift, drag, and moment coefficients.

In the Automotive Engineering course, the Baja vehicle (less than a minute's walk from the classroom) makes a superb visual aid. Everything from suspension geometry to rack-and-pinion steering is much easier explained when standing before a completely open vehicle. Baja team members often deliver the explanations to their peers.

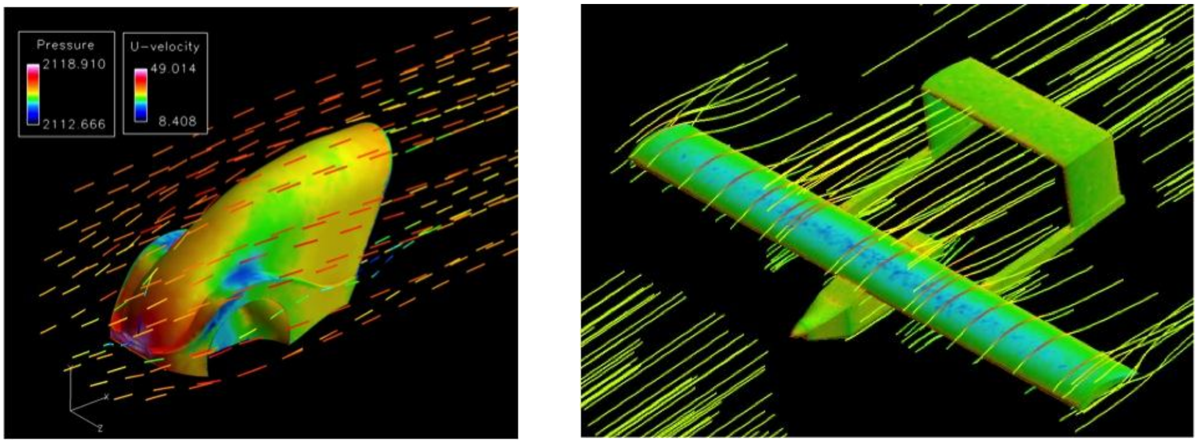

Figure 6: CFD airflow analyses for proposed HPVC body (left) and Aero Design craft (right)

The Automotive Engineering instructor also requires students to deliver 10-minute presentations on an automotive-related topic. Baja students have used this time to describe to their peers design decisions such as suspension configuration tradeoffs between bump steer, camber gain, and jounce travel.

External engineering competitions, in general, make for excellent senior design (or "capstone") projects. They provide a clear goal, predefined design constraints, rigid deadlines, and impartial external project evaluation. Additional requirements for written and oral technical communication, especially to an unknown audience, are valuable.

Throughout the entire project, competition-based-capstone students recognize that their product will be competitively appraised; shortcomings in the design or construction will become evident in rather public ways. This subtle pressure, the potential for glory or embarrassment beyond a final grade, typically drives students toward a product superior to what they would have otherwise produced. Several authors report competitive projects, as opposed to those done in isolation simply to create a functional prototype, dramatically increase student motivation and the quality of results.[3,4,20] Yet though the competition-based capstone experience is excellent, it is hard to achieve competitive results without the years of cumulative experience and continuity possible with a multiyear volunteer team.

Institutional Support

External competitions place significant demands on the participating institution. The demands can be so high, in fact, that some argue that they are not worth the cost unless educators are very intentional in integrating curriculum learning objectives with competition team efforts.[21]

Though not true of every competition, the projects described here consume a great deal of physical space for construction. The primary workspace available for these projects at ONU measures 30 ft. x 40 ft.; this seems fairly large, until one envisions it shared by a Baja vehicle and tool carts, two recumbent bicycles, one or two model aircraft with up to 10 ft. wingspans, and several football robots. The space is also currently shared with a golf cart and small boat, both of which are being converted to autonomous operation by senior design teams, as well as space for class projects for courses throughout the curriculum.

The competitions also place significant demands on design and analysis software availability. While only one software package was purchased specifically for use by the competition teams, the teams spend a great deal of time using the CAD, FEA, and CFD software available to all students on the few powerful computers capable of handling large models. Sometimes regular classroom students find themselves at odds with team members as each are pushed against deadlines for computational assignments.

The cost of external competitions is also substantial. Often material purchases significantly exceed that of the average senior design project. And costs for the team to travel hundreds of miles – or across the country – for the competition frequently surpass the material costs. The ONU College of Engineering is very fortunate to have received an endowment specifically created to fund competition teams. Before this endowment, the Baja and Aero Design teams were much more restricted in materials and travel, forced to reuse costly components beyond their lifespan, and much more dependent on the generosity of sponsors. And without this fund, participation in the HPVC and other recently added events throughout the college would have been impossible (unless somehow funded entirely by students or external donors).

Assessment

The effectiveness of external engineering competitions as undergraduate educational experiences is challenging to quantify. Students who actively participate in these teams certainly vouch for their usefulness. Anecdotally, three ME seniors surveyed before their 2011 graduation separately volunteered a suggestion that some competition project team participation should be required for all engineering students, at least for one or two terms. And many ME alumni invited back to share their experiences and advice with the new freshmen class point out that their participation on one of the design teams was invaluable.

Several even directly credit their competition experience with landing the job of their choice. One student said, "Baja is the reason I got my job. Four years of design, teamwork and leadership are what Polaris wants to see from students. If I didn't do Baja, there is no way I would have ever been given this opportunity." [22]

Conclusions

This paper describes four external engineering competitions employed by the Mechanical Engineering Department at Ohio Northern University as a supplementary means of satisfying the full spectrum of educational objectives and broadening the educational experience of many students. Educational objectives are satisfied directly through competition requirements as well as by integration of competition topics and tasks into the curriculum, whereby even students not participating may benefit. Educational experiences are enriched as the projects boost student engagement and provide advantages in both learning and motivation.

Fielding a number of different competition teams enables students to choose a project they will enjoy and a comfortable level of time commitment. All these advantages come at a significant price in terms of space, computing resources, and financial burden. But the rewards are rich for the student who is able to gain a knowledge of and confidence in many real-world engineering situations which they may otherwise not experience before graduation.

Appendix

Program Educational Objectives for Mechanical Engineering at Ohio Northern University

Our graduates will be able to

1. apply the principles of mechanical engineering in order to develop or improve products and technologies.
2. communicate effectively with a variety of audiences and work efficiently in multi-disciplinary teams.
3. work in a competent and ethical manner, recognizing the impact that engineering has on society.
4. continue their professional development through graduate studies and independent learning.

ABET – Criteria for Accrediting Engineering Programs, 2012-2013

General Criteria 3. Student Outcomes

The program must have documented student outcomes (a) through (k) that prepare graduates to attain the program educational objectives.

(a) an ability to apply knowledge of mathematics, science, and engineering
(b) an ability to design and conduct experiments, as well as to analyze and interpret data
(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
(d) an ability to function on multidisciplinary teams
(e) an ability to identify, formulate, and solve engineering problems
(f) an understanding of professional and ethical responsibility
(g) an ability to communicate effectively
(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
(i) a recognition of the need for, and an ability to engage in life-long learning
(j) a knowledge of contemporary issues
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

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