AC 2010-79: EXPERIENCES OF USING FORMULA SAE AS A CAPSTONE DESIGN PROJECT

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Experiences of Using Formula SAE as a Capstone Design Project

Abstract

Capstone Design courses are, by their nature, intended to test the abilities students have gained over their college careers and to provide a design experience that simulates real-world engineering. An important factor in giving students a valuable Capstone Design experience is the selection of an appropriate project. A good project for this purpose should have appropriate technical rigor and allow students to focus as much as possible on engineering design rather than on logistical activities like fundraising. Further, the work done by students in the course should be assessable, both for the purposes of accreditation and for assignment of grades. Additionally, the deadlines imposed must be appropriate, and evaluation criteria need to be established.

One solution for many of the project planning aspects of Capstone Design is a student engineering competition, many of which are sponsored by professional societies. The Mechanical Engineering program at York College of Pennsylvania has been using Formula SAE® as a project since 2007, with one or both authors advising the project since 2008. We discuss the pros and cons of such a project as a Capstone Design experience, including its technical merits and scope; how it lends itself to assessment of course outcomes and of student work; time spent on fundraising rather than on design; the effect of imposing a one-year design cycle on this project, when other schools have a multi-year cycle; keeping students focused on the educational rather than competitive aspects of the project; and dealing with conflicts that arise due to the externally-imposed deadlines. We find that such a project is an attractive option for a small program, with its benefits outweighing its downsides. We also give some suggestions for a program that may be considering using this particular project for Capstone Design, including expectations of performance, building from one year to the next, and the limitations of FSAE in terms of assessing course or program objectives and student work.

1.0 Background

1.1 Capstone Design at York College of Pennsylvania

Under the Carnegie Classifications of Institutions of Higher Education, York College of Pennsylvania is a four-year, medium-sized private four-year institution with professions plus arts and sciences and some graduate coexistence. Mechanical engineering majors make-up about 3% of the college’s annual graduates (about 20 students) and there are no graduate programs in engineering. York College of Pennsylvania has five full-time mechanical engineering faculty members.

There are a number of challenges in administering a successful Capstone Design program at schools like York College of Pennsylvania with small student and faculty populations. With
only five faculty, we are limited in the number of faculty available to teach Capstone Design and we are limited in the breadth of faculty expertise in providing technical guidance for projects. A small student population can have benefits and challenges. There is little published data on per student spending for Capstone Design project costs or administrative resources, thus it is difficult to make meaningful comparisons to large schools in these areas. However, we can conclude that a small student population results in fewer project choices. Throughout the paper we will use the term “small program” to refer to schools with student and faculty populations comparable to ours.

Capstone Design at York College of Pennsylvania is a two-semester course taught by one or more faculty. The course enrollment can range from 10–25 students depending on the size of the senior class. The Mechanical Engineering program has a long history of using a single, competition-based project as the only Capstone Design project for the entire year requiring all 10–25 students work together on one project. The school has participated in a variety of competitions including: Walking Machine Challenge SAE (2003, 2004), Baja SAE (2005), Supermileage SAE (2006), and Formula SAE (2007-2010). With the addition of an Electrical and Computer Engineering major at the college, we were able to offer two Capstone Design projects in 2010: Formula SAE and the Intelligent Ground Vehicle Competition. The Capstone course is 3 credits per semester with one 90-minute class period each week. The class time is used for a team meeting. No formal instruction occurs and students are not required to buy a textbook or complete structured homework or exams. A final course requirement is that all students must take the Fundamentals of Engineering exam.

The Mechanical Engineering faculty at York College structure the Capstone Design project to simulate a real-world team engineering experience. Students are evaluated on a diverse set of criteria in a manner similar to an employer conducting a performance review. These criteria include technical competency, teamwork skills, oral and written communication skills, and project management skills. The overarching goals for Capstone Design are to help students develop increased confidence in their engineering abilities and a positive impression of their overall educational experience at York College of Pennsylvania.

1.2 The Formula SAE project

Formula SAE (FSAE) has been offered since 1978, originally under the name “Mini-Indy” (a nod to the still-thriving Mini-Baja competition that inspired it). The premise behind the project is that the student team is developing a prototype vehicle for the target market of the amateur weekend autocross racer. Students then “sell” their design to a fictional manufacturing company which evaluates the design on its performance features and its viability as a production vehicle.

Several different competition events are used to assess vehicle performance and manufacturability. Static events involve presentations and written documentation while dynamic events demonstrate the capabilities of the vehicle. The static events include a cost report
detailing the production cost of the vehicle, a marketing presentation focusing on vehicle manufacturing processes and costs, a critical review of the design by judges having vehicle design expertise, and a technical safety inspection. The dynamic events consist of a straight-line acceleration test, a handling test on a figure-eight-shaped course, an autocross event around a one-mile track, a twelve-mile endurance event, and a fuel economy event. These competitions are held in six locations worldwide, including two in the United States.\textsuperscript{2,3}

The nature and history of this project mean that there are many different types of teams that enter into it on a yearly basis. There are teams that have been participating in the event from its inception, and are thus free to “tweak” already successful designs, while teams with a shorter history need to perform more sweeping design changes year-to-year. Some teams are supported through extracurricular clubs while others receive substantial academic credit for participation in the project. Larger schools tend to have larger teams, some with 50 or more team members, whereas smaller schools may have fewer than 10 students on a team. Schools also vary in how much time is invested in developing a vehicle. Some teams complete the entire project in one year; others use a design cycle of two or more years. Lastly, team budgets vary from about $15,000 for the smaller, less well-funded teams to $80,000 or more for the teams with more established funding sources.

1.3 Benefits of student participation in FSAE

There are many qualities of FSAE that make it a rewarding Capstone Design project. All systems of the vehicle are open to design by the student team, allowing students to focus on various subdisciplines within mechanical engineering.

The intake system, as it has to funnel air first through a 20 mm restrictor and then into the engine, allows students to apply fluid mechanics principles. The design of the exhaust and muffler system also provides experience with fluid mechanics, with some applications of acoustics and wave motion possible in a resonant-style muffler.

Structural analysis appears throughout the vehicle design. A frame capable of supporting the dynamic loads of the vehicle must be designed. Suspension members that support loads necessary to keep the car on the track in a 1.5-g turn must be created. A differential is usually necessary to transmit the engine output to the rear axle, which requires a housing that can support the applied torque. All parts of the car must be mounted to the frame, requiring appropriate selection of support points.

Other topics factor more subtly into the vehicle’s design. Ergonomics must be considered, as the vehicle has to accommodate the 95\textsuperscript{th} percentile male while allowing the driver to exit in fewer than five seconds. The car must decelerate from a frontal impact by use of an attenuator that transmits loads safely through the frame and around the driver. Student designers must choose appropriate materials for the different parts of the car, considering fatigue life of parts, yield or rupture strength, proximity to a heat source (the engine and exhaust) and overall weight.
In addition to the diverse technical demands of the project, many other benefits have been documented by various schools. Kettering University surveyed alumni and found that students who participated in the SAE collegiate design series found their educational experience was enhanced, they were better prepared for employment, and they had improved perceptions of the university. Montana State University noted the students participating in FSAE tackled challenging design problems, learned collaboration skills through managing interfaces between systems, and dealt with project management issues such as budgeting, decisions to make or buy components, assembly sequencing, and quality assurance. Clarkson University discussed the benefits of student competitions in general, including FSAE, Concrete Canoe, Steel Bridge, and FIRST Robotics. This institution emphasized that students participating in these competition-based activities were given opportunities to apply classroom learning to real-world projects, to learn first-hand how manufacturing impacts design, to improve leadership and interpersonal skills, and to develop skills that are marketable in a job search. California State Polytechnic University-Pomona found that many industry recruiters specifically request interviews with students who participate in an SAE project, indicating industry values the self-motivation, technical skills, and experience developed by these students. While all of these schools also note the challenges in funding and administering such a demanding project, they convey an overall positive impression of the project benefits to their programs and their students.

1.4 Summary

The goal of this paper is to evaluate the advantages and disadvantages of using FSAE as a Capstone Design project at a small program. A critical concern in choosing a Capstone Design project is determining whether the project achieves the desired learning goals. Section 2 discusses the Capstone Design objectives and assessment methods used at York College of Pennsylvania to evaluate the educational effectiveness of FSAE. In addition to learning, there are many practical factors that affect the selection of a Capstone Design project. Section 3 discusses these other factors including project availability and timing, fundraising, faculty expertise, constancy of the project, institutional expectations, and competition versus education. Section 4 presents results from an alumni survey evaluating student impressions of the project. Finally, Section 5 discusses conclusions and gives recommendations for small programs considering using FSAE as a Capstone Design project.

2.0 Capstone Project Selection and Learning Goals

The Mechanical Engineering faculty at York College of Pennsylvania have identified desired learning goals for the Capstone Design course. These learning goals have been developed into course outcomes. Since fall semester 2008, the faculty in Mechanical Engineering have performed a direct assessment process for outcomes in all courses. The Capstone Design assessment results will be used to evaluate the ability of the FSAE project to meet our learning
goals. This section will discuss the assessment process, specific learning objectives for Capstone Design, and an evaluation of the assessment process results.

2.1 Course assessment process used at York College of Pennsylvania

To begin, the instructor of each course develops a set of course outcomes which are then tied to the ABET a-k criteria. Student activities, such as homework problems, exam problems, and lab reports, are selected to use for direct assessment. One or more activities are assessed for each course outcome. The work of each student is evaluated as exceeding expectations (E), meeting expectations (M), or below expectations (B). The course instructor then completes an Assessment Evaluation Form for each student task that is assessed. Students that do not pass the course are not included in the assessment. At the end of the semester, faculty members do an overall course evaluation that documents the course description, course grade distribution, modifications made to the course, an overview of the Assessment Evaluation Forms, and proposed actions for course improvement. This method has proven to be effective in helping faculty members reflect on teaching methods and develop strategies for course improvement.

An example of an Assessment Evaluation Form is shown in Figure 1. It has several sections, starting with the instructor’s evaluation of the level of difficulty of the assignment (easy, moderate, or difficult). Next, the instructor writes a description of how they expected students to perform on the task. Observational notes are then written which evaluate student performance on the task, including quantifying the number of students exceeding (E), meeting (M), or below (B) expectations. An overall assessment is given for the task (E, M, or B) and the instructor writes corrective actions that will be taken, if required. Finally, the instructor copies an example of student work for each category (E, M, or B).
Assessment Evaluation Form

Course: Capstone Design I  
Semester: S09  
Instructor: 

Course Outcome Being Assessed: CO-ME400-2 – An ability to learn independently to complete a design problem successfully. (i)

Assessment Source: (e.g. homework, quiz, exam problem, paper, etc.): Final Technical Memo

Level of Difficulty: (Easy, Moderate, Difficult): Difficult

Expected Performance Level: I expected students to do a significant amount of independent learning to complete their design tasks during the first semester of Capstone Design. For both the FSAE project and the IGVC project, students designed systems that required significant learning beyond what they have learned in the classroom. As examples, the FSAE team needed to learn about vehicle suspensions and exhausts, two topics that are not explicitly taught in their formal coursework. I anticipated students coming to the faculty to get help throughout the semester. In actuality, faculty members were asked questions infrequently, indicating students did the vast majority of their design work independently. Students that did not pass the course (grade lower than 2) are not considered in this assessment.

Observational Notes: 8 of the 13 technical memos exceeded expectations regarding the students ability to learn independently. These memos demonstrated students were able to complete successfully sophisticated designs of systems that required extensive, in-depth knowledge of devices or systems that they were largely unfamiliar with at the beginning of the semester. 4 of the 13 memos met expectations. These memos demonstrated students were able to learn about their systems and apply engineering analysis to the design of their systems. The level of design work was not as sophisticated as the students that exceeded expectations. 1 of the 13 memos was below expectations.

Overall Assessment: E – Exceeds Expectations; M – Meets Expectations; B – Below Expectations

Corrective Actions: None. I am satisfied that our students have demonstrated their ability to learn independently and apply their engineering analysis skills to applications that require to them to extend what they learned in courses.

Attach samples of student work for each case, E, M and B.

Figure 1: Example Assessment Evaluation Form

Assessment Evaluation Forms and the overall course evaluation have been used to assess the FSAE project for two semesters. Since the Mechanical Engineering program at York College of Pennsylvania has chosen this assessment method, part of our determination of how effective this project is as a Capstone Design experience necessarily includes whether the chosen course outcomes can be assessed in this way through FSAE.
2.2 Capstone Design course outcomes and assessment methods

To develop outcomes, the mechanical engineering faculty first agreed upon a course philosophy for Capstone Design. The projects should be rigorous and complex, requiring students to invest approximately 10 hours per week throughout both semesters of the course. Each student should be challenged to learn independently and apply their design skills to applications that are substantially different from what they have encountered in their coursework. It is also important for students to work through a comprehensive design process including design, fabrication, and experimental testing to evaluate the quality and accuracy of their design. Students should work in a diverse team and develop skills in managing team schedules, team budgets, and team dynamics. This includes implementing problem-solving skills to maintain collegiality when there are disagreements on design decisions or differences in personalities or working styles. Students should also be able to substantiate design decisions with thorough analysis and clear and concise oral and written communication. In all aspects of Capstone Design, students are expected to demonstrate professional and ethical behavior.

These philosophical ideas are articulated in the outcomes for Capstone Design which appear in the course syllabus as shown below. The letters after each outcome refer to the ABET a-k criteria.

Students completing this course should have:

Course Outcome 1: An ability to design, fabricate, and test a mechanical or thermal system. (b, c, e, k)

Course Outcome 2 – An ability to learn independently to complete a design problem successfully. (i)

Course Outcome 3 – An ability to work professionally within a team to complete a project on schedule and within budget. (d, e, f)

Course Outcome 4 – An ability to use written and oral communication to describe the data, calculations, analysis, and experimental results used to substantiate design decisions. (b, g, k)

Course Outcome 5 – An ability to recognize ethical dilemmas and make appropriate decisions. (f)

Several methods have been used to assess student work in Capstone Design to assign grades and implement the outcomes assessment process. For week-to-week evaluation, students have provided self progress reports and maintained a laboratory-style engineering notebook where they have recorded all design work and meeting notes. The course instructor grades these self reports and notebooks weekly. Students have written individual learning goals based upon the course outcomes and then documented achievement of their goals through a design portfolio.
The design portfolios have consisted of a written reflection and supporting evidence of learning such as calculations, CAD models, photos, timelines, and reports. Peer evaluation rubrics have been developed for students to assess each other’s teamwork skills and contributions to the project. Individual technical memos and team design reports have been used to assess design skills and written communication skills. At the end of the first semester of Capstone Design, students have given a design review presentation for an interdisciplinary group of faculty, representatives from industry, and other students. All audience members were asked to fill out evaluation forms after the presentations, which were used to assess the students’ technical work and presentation skills. Finally, students have been given a survey at the end of the second semester of Capstone Design to assess their confidence level in each of the course outcomes.

2.3 Assessment results to evaluate FSAE as a Capstone Design project

Course Outcome 1: An ability to design, fabricate, and test a mechanical or thermal system. (b, c, e, k)

Assessment of technical memos, engineering notebooks, design portfolios, and design reports indicate that almost all students are meeting or exceeding faculty expectations in their design and fabrication abilities, but the testing component of this outcome appears to be weak. Because our team is relatively new to FSAE, for the past three years we have done end-to-end design of the vehicle. As a result, our students usually finish building the FSAE vehicle mere hours before leaving for the competition and our team has been weak on demonstrating experimental validation of the vehicle design. The design judges at the FSAE competition have emphasized experimental validation is critical to do well in the design judging event. In the future, we will do less comprehensive design and instead focus on one or two specific subsystems each year and leave the rest of the vehicle largely unchanged. This will shorten the design and fabrication time and give the students more opportunity to do experimental validation. In this case, the FSAE competition, through its emphasis on experimental validation, is actually motivating the program to emphasize the deficient component of this learning goal.

There are some tasks in completing the FSAE vehicle that are less technically rigorous, such as the body design. Occasionally students gravitate to these less rigorous tasks to minimize their workload or to avoid imperfect team dynamics. This effect has been mitigated, however, through assessment of individual technical memos and engineering notebooks. Students must contribute consistently and effectively to the design and fabrication effort, as shown through these documentation methods, to pass the course.

On the course survey, all students indicated they agreed (29%) or strongly agreed (71%) with the statement “I feel confident in my ability to design, fabricate, and test a mechanical or thermal system.” Overall, we can conclude the students participating in FSAE left the project with the desired self-efficacy in their design abilities. In the future, focusing the design effort will allow students to do more experimental testing. The relative weakness of the testing portion of this
outcome is not due to the choice of FSAE as a project. Rather, this appears to be a temporary situation related to our relatively short history with the project. While we believe testing is an important aspect of Capstone Design, students at York College of Pennsylvania have many opportunities to engage in laboratory activities and projects throughout the curriculum so students involved in the first few FSAE teams were able to gain testing experience through other courses.

If programs are considering introducing FSAE as a Capstone Design project for the first time, the time latency on experimental testing could be mitigated in several ways. Teams could start by using a multi-year design cycle. In this model, students could conduct experimental testing on subsystems instead of the complete vehicle. The primary disadvantage is that groups of students would miss out on the opportunity to develop a complete prototype vehicle and compete. A second strategy would be to introduce FSAE as a club activity to build institutional knowledge before making it a Capstone project. Finally, a program new to FSAE could take a combined approach. This may involve placing the project under the auspices of a student club, allowing future expertise to be built. In the meanwhile, the program could offer one or more Capstone Design projects regarding design, fabrication and testing of a specific subsystem of the FSAE prototype (say, suspension or intake design).

Course Outcome 2 – An ability to learn independently to complete a design problem successfully. (i)

Technical memos, design portfolios, and design reports have demonstrated that nearly all students in Capstone Design engage in significant independent learning. Many of our students start the project with little, if any, detailed knowledge of vehicle design. Students have successfully designed systems such as the brakes, suspension, intake, and exhaust through extensive independent learning. Students rarely seek out assistance from faculty advisors to understand fundamental design principles for their specific system or to figure out how to start their design work. (As discussed later, low-level assistance such as this is prohibited by FSAE rules; see Section 3.) Instead, students progress to advanced stages of design independently and then ask sophisticated questions to draw upon the course instructors’ broader depth of experience. It is also surprising that students seldom contact faculty who are not teaching Capstone Design, even though the college encourages an open-door policy where students are welcome to ask questions of faculty even outside of formal office hours. On the course survey, all students indicated they agreed (21%) or strongly agreed (79%) with the statement “I feel confident in my ability to learn independently to complete a design problem successfully.” The FSAE project does an exceptional job of challenging students to learn independently, and our students have demonstrated remarkable achievement in this area through successful completion of the project with minimal technical guidance.

Course Outcome 3 – An ability to work professionally within a team to complete a project on schedule and within budget. (d, e, f)
This is the outcome where we have the greatest potential for growth, both concerning professional teamwork and schedule and budget management. The competitive nature of the FSAE project brings out the best in some students, and the worst in others. Students who invest heavily in the project have a tendency to overvalue their own contributions and undervalue the contributions of others. This can lead to authoritarian decision making and inefficient team dynamics. Teamwork skills are particularly challenged towards the end of the project when the competition deadline approaches and student stress levels are high. As a result, the most significant teamwork challenge for our students has been managing team conflict.

Engineering teams can produce better results when they value and utilize diverse ideas, but the process of integrating and reconciling these ideas often leads to conflict. This means that an important aspect of assessing teamwork skills is determining whether each student is effective in handling critical team conflict. Even during tense phases of the project, we expect students to demonstrate several behaviors to be considered effective in teamwork skills including being respectful of others, acting professionally, providing constructive criticism and not engaging in personal attacks, and being able to identify objectively strengths and weaknesses in themselves and others.

Assessment of these behaviors has proven to be challenging. Past conflict has tended to factionalize past teams. Student assessments of their peers have shown blocs of students sharing one view on contentious issues uniformly giving poor evaluations in all criteria to those holding the opposing view. This indicates many students were not able to maintain objectivity to assess strengths as well as weaknesses after team conflict. There have also been cases where specific students engaged in unprofessional conduct that had substantial and lasting impacts on the team’s effectiveness.

Despite these challenges, students report via surveys that they feel capable of working within a team. In fact, course surveys indicated that all students agreed (86%) or strongly agreed (14%) with the statement “I feel confident in my ability to work professionally within a team to complete a project on schedule and within budget.” It is clear that the competitive nature of the FSAE project challenges students to learn conflict management skills, but even after intense clashes students ultimately leave the experience confident in their teamwork abilities.

To help students develop more effective conflict management skills, the faculty have begun conducting one-on-one performance reviews with each student on the team. During these reviews, the faculty and students discuss what they see as the students’ strengths and weaknesses. The faculty then help each student to formulate specific targets for improvement. The reviews also give students an opportunity to notify the faculty of any issues of concern which gives the faculty members an opportunity to address such issues before they lead to disruptive incidents. To further improve assessment practices, in the future we plan to have students write self-reflections in their design portfolios about their strengths and weaknesses
when working in a team, including citing specific examples of each. This will allow the faculty to assess each student’s level of insight and growth.

The FSAE project, as implemented within Capstone Design, requires students to coordinate design efforts in a large team, manage part ordering and fabrication timelines, and work within a fixed budget. Assessment through the design review evaluations indicates our students need to improve their schedule and budget management skills. Many of the presentation reviewers commented about the need for a master Gantt chart and several addressed the need for systems engineering including designing weight and cost budgets. In the future, we plan to implement formal instruction in project management and have more structured schedule and budget management requirements for the course. FSAE sufficiently challenges students in critical project management skills and assessment shows that we can improve student learning in this area.

Course Outcome 4 – An ability to use written and oral communication to describe the data, calculations, analysis, and experimental results used to substantiate design decisions. (b, g, k)

Oral and written communication skills can be utilized by students and then assessed through any Capstone Design project, but the FSAE project offers some unique advantages. While individual writing assignments are most useful for assessment purposes, there is still significant value in engineers learning to work collaboratively on a team report. The FSAE competition requires the submission of a team design report which is then evaluated by judges. Thus, FSAE provides opportunities for students to engage in team writing activities and to get feedback from experts about their work.

The surest way to score poorly in the FSAE design event is to have a student answer a judge’s question with, “I don’t know why we designed it that way – it’s just how they did it last year.” Individual writing activities, such as the technical memos, are being used by the York College of Pennsylvania FSAE team to create a technical library to ensure design knowledge is transferred from team to team. All students get electronic access to memos that have been written in previous years. For this critical knowledge transfer to occur, the memos must effectively communicate the details of the design process for each component on the vehicle. On individual tasks, nearly all students meet or exceed faculty expectations for written communication skills. Because the FSAE competition requires comprehensive vehicle knowledge, there is special motivation for students to engage in meaningful and relevant writing activities. Their success in these writing activities is being used to benefit future teams.

Like written communication, FSAE utilizes oral communication skills but not in a way that is effective for assessment purposes. Not all students get the opportunity to present at the competition, making assessment of oral presentation skills for every student impossible. Further, one of the two presentations at the competitions is closed to the public, while the other usually takes place in a loud tent, with multiple design judges interviewing students simultaneously.
preventing the faculty advisor from observing all students concurrently. Though not useful for assessment, these activities are valuable learning opportunities and the competitive nature of the presentations motivate students to rigorously prepare and practice. In the past, students have spent many hours compiling documentation and studying their designs in preparation for the design event. After the event, students receive feedback from design judges and this information is utilized by future teams to create a more competitive design.

At the end of the first semester of Capstone Design, a design review presentation is used to perform assessment of oral presentation skills. It also allows students to practice presenting and answering questions in a high-stakes environment. The audience is usually about 50 people consisting of faculty members from all engineering disciplines, other students, and about 15 industry representatives, often managers who make hiring decisions for co-op students. Each student gives a short description (2-3 minutes) of their individual design work. While brief, this allows the course instructor to assess individual oral presentation skills and provide feedback to each student. The presentation evaluation rubric used by the audience is shown in Figure 2. Nearly all members of the three audience groups (students, faculty, and industry representatives), rated the presentations competent or better in all categories: effectiveness of communication, organization and scope, technical content, design and analysis quality, quality of visual aids, interesting and engaging, and ability to answer questions effectively. While this type of presentation can be used for any Capstone Design project, the FSAE competition requirements motivate students to prepare and then utilize the audience feedback.
Design Review
Capstone Design
2009

Team (circle one): IGVC / FSAE  Evaluator Affiliation (circle one): Faculty / Industry / Student

Please provide an assessment of each team’s performance overall and then fill in the written comments sections. You may address comments to specific students, if desired.

<table>
<thead>
<tr>
<th>Presentation</th>
<th>Exceptional</th>
<th>Competent</th>
<th>Marginal</th>
<th>Unsatisfactory</th>
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<tbody>
<tr>
<td><strong>Effectiveness of communication</strong>&lt;br&gt;Appropriate speech rate, volume, clarity, use of gestures/movement, use of language (grammar, pronunciation, correct use of technical vocabulary)</td>
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<td><strong>Organization and scope</strong>&lt;br&gt;Presentation well-organized and easy to follow; transitions between topics clearly signaled; scope and depth of the presentation congruent with the expertise and expectations of the audience and allotted time</td>
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<td><strong>Technical content</strong>&lt;br&gt;Presenters clearly explained their arguments and provided sufficient evidence for their claims; presentation significantly increased audience’s knowledge of topic; presenters clearly defined terms/acronyms when needed</td>
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<tr>
<td><strong>Design and analysis quality</strong>&lt;br&gt;Design problem well-understood by presenters; designers considered sufficient variety of solutions; depth of analysis satisfactory; reached well-supported conclusion</td>
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<td><strong>Quality of visual aids</strong>&lt;br&gt;Well-written; engaging; emphasized points without distracting focus from technical content</td>
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<td><strong>Interesting and engaging</strong>&lt;br&gt;Audience learned something new; presenters enthusiastic about their work; captured audience’s attention/curiosity; raised thought-provoking questions and insights</td>
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<td><strong>Ability to answer questions effectively</strong>&lt;br&gt;Answered questions with appropriate detail and knowledge; not confrontational with questioners; showed interest and respect for questions</td>
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Figure 2: Evaluation form for the design review presentation
Course Outcome 5 – An ability to recognize ethical dilemmas and make appropriate decisions.

FSAE provides some areas in which ethics take part. The cost report, which is submitted by each FSAE team for judging, allows room for an unscrupulous team to understate the actual vehicle costs. Unethical students can lie to judges about vehicle capabilities or possible manufacturing methods. To be sure, these unethical behaviors may be caught by alert judges and attentive faculty. However, the ability to assess this outcome relies upon identifying the positive as well as the negative. Ideally, there would be some observation of especially ethical behavior from all students. As it stands, however, evaluation of this course outcome relies upon the absence of known unethical behavior. To be assessed properly, this outcome requires students to engage in activities outside of the FSAE project.

A possible solution to the assessment problem is to use a direct assessment method like the one developed by Washington State University. This method involves asking students to read a description of a complex, open-ended engineering problem. Students are then given general discussion prompts such as: describe the primary issues raised; consider all of the impacts; choose one or two approaches/possible solution paths that seem most reasonable and state your rationale. To perform assessment, students are instructed to record their ideas on each of the prompts on poster board. After sufficient time, students share their ideas with the rest of the class. While students work and during the sharing time, the course instructor can use the Professional Skills Assessment Rubric to evaluate each team’s performance. After completion of the task, students can then use the rubric to self-evaluate. We plan to develop an engaging, open-ended engineering problem pertaining to the FSAE competition to perform ethics assessment in the context of the project.

2.4 Summary of assessment results for the FSAE project

A structured assessment process has been implemented at York College of Pennsylvania to determine whether the FSAE project is enabling our students to achieve course outcomes. In some cases, the assessment process itself has led to significant improvements in the course which promote consistent participation by all students in all outcome areas. It has also been shown that the FSAE project provides unique and compelling learning opportunities that are not useful for assessment purposes.

Overall, the FSAE project is challenging students to improve their design, fabrication, and testing skills. Students are also engaging in extensive independent learning to complete the project. Students utilize oral and written communication skills during the project and they are challenged to develop project management skills. On the negative side, the competitive nature of FSAE seems to intensify team conflict. The course instructors will adjust the project scope and structure to attempt to eliminate the detrimental discord, but more time is needed before we can assess whether the team dynamics are too challenging and prevent students from learning
effective teamwork skills. Finally, assessment of ethics in the context of students working on the FSAE project is problematic because faculty cannot directly observe all instances of either ethical or unethical behavior during the project. We plan to implement a direct assessment method which would require students to participate in an artificial activity, but the activity can be written to relate to the project.

3.0 Additional project considerations

The educational aspects discussed above are of great importance in determining the effectiveness of a Capstone Design project. However, the educational value is but one facet of the overall evaluation of the suitability of a project. This section will detail a selection of non-educational considerations in a Capstone Design project, and how FSAE meets these aspects from the perspective of a small institution.

3.1 Project availability and timing

One of the main advantages to using FSAE as a Capstone Design project at a small program is its availability. FSAE is a rather stable project, having been contested for thirty years. This is clearly an advantage when examining some common alternatives for Capstone Design projects.

Industry-sponsored projects are a common theme in Capstone Design courses. However, this method is less viable for a small program. With a small graduating class, there may not be enough personnel to perform all projects that are proposed. In addition, it is often challenging to align the company’s timeline with the academic calendar. These factors may make potential industrial partners reluctant to propose Capstone Design projects. Relationships built between the program and their industrial partners may be damaged if certain companies consistently have difficulty getting a design project to run.

Another alternative to a student competition like FSAE is faculty-sponsored projects. At a smaller institution, especially one with a stronger focus on instruction rather than on research, it may be difficult to find enough faculty projects to suit even a small class. These methods require faculty to do significant planning and preparation, including determining what constitutes an appropriate scope for a project and setting a reasonable date for completion.

An advantage that FSAE provides over both alternatives is that the background work in identifying appropriate deadlines, finding a method of evaluating a prototype, and finding experts in the field to assist in project evaluation are all done by SAE International. By no means does this eliminate the work that needs to be done by faculty, but it has the distinct advantage of allowing the faculty to focus on needs specific to the Capstone Design course. The externally-imposed deadline also has instant credibility with the students. Clearly, if the majority of the 120 registered teams can finish the project in the time allotted, the deadline must be reasonable.
3.2 Fundraising

FSAE is a rather expensive proposition. The average spent in the previous three years at York College of Pennsylvania has been around $18,000, including travel costs. The Mechanical Engineering program seeds the team budget with the first $5,000; the remainder of the funds required for the team to build their prototype vehicle and travel to the competition must be raised by the team. Fundraising events in the past have included solicitations of local businesses, in-kind donations, food sales and t-shirt sales, among others. On one hand, this can be argued as a good aspect of the project – if students have an interest in starting their own business or in consulting engineering, practice with speaking to potential financial backers is valuable.

The drawback to this aspect of the project is represented by the non-industrial methods of fundraising employed by the team. While soliciting support from corporate representatives is valuable engineering experience, organizing a t-shirt sale or selling sandwiches is not nearly as applicable. Further, these grassroots fundraising activities are usually more time-consuming than visiting a local company, and are less lucrative as well.

The underlying reason that fundraising is a drawback has to do with the goals we have set for our students’ Capstone experience. The time spent on trying to find money must come from some other necessary activity. Usually, this means that the project management aspects, such as budgeting and creating timelines, become secondary to procuring enough funds in the first place. This can be exacerbated at a small program where variability in the team size can mean that a smaller class, with a smaller pool of personnel-hours available for the project, must spend more time per person in procuring money.

Further, for a small program, faculty and administrative resources to assist with many of these fundraising activities are nonexistent. The campus office tasked with soliciting donations from local businesses may either be uninterested in helping one particular program’s needs (instead considering those of the overall college community), or may not have the time to provide detailed feedback about how to write a solicitation letter. A larger institution may have an outreach office for the engineering school, or even for the Mechanical Engineering program. These external activities are a necessity, because unless the engineering program at a given small program is so fortunate as to have an established endowment for Capstone Design, internal funds to support the project are likely to fall well short of the overall budget.

An effect of the need to fundraise is the desire to get the best possible return on investment. In the case of FSAE, the expense incurred year-to-year tends to breed inertia against changing to another project. On one hand, reuse of equipment and parts brings down the real cost of the project, increasing the return on expended funds. On the other, certain parts of the car (like the suspension and frame) cannot be reused, and are thus a recurring cost.

3.3 Faculty expertise
Part of advising a Capstone Design project is contributing engineering expertise where appropriate. The FSAE rules limit this contribution to “general engineering and engineering project management theory,” meaning that the faculty member’s engineering role is limited for all competing teams.³ This restriction is helpful for a small program because it is unlikely that a small faculty has an automotive engineering expert or amateur autocross racer on staff.

Further, the definition of the advisor’s technical role helps promote independent learning. The students cannot, by rule, ask the advisor for detailed design help. Rather, students are limited to asking general questions, which the faculty advisor can reasonably answer by asking probing questions. These return queries, if well-chosen, can determine whether the student has done appropriate research on the subject at hand.

An industrial or faculty-developed Capstone Design project would not have this restriction. In the case of an industry-sponsored project, the industrial sponsor may give more assistance than the faculty deem appropriate. A faculty-sponsored project can exacerbate this further, as students are accustomed to getting assistance with difficult problems from faculty. The faculty member who has proposed the project becomes a natural person to ask for help. Students may expect to be able to tap this faculty member’s expertise much more in a faculty-sponsored project than a competition like FSAE.

3.4 Constancy of the project

FSAE is not a variable project. While the rules are modified from one year to the next, these changes are not extensive. Therefore, the challenge is relatively constant. In a sense, as time goes on and the institution gains expertise with the project, the challenge diminishes from year-to-year assuming knowledge transfer is effective.

While the relative constancy of the challenge may seem to be a benefit on the surface, it can be a disadvantage for a small program seeking to use FSAE as a Capstone Design project. If the class size is small, the amount of work per student will be high. Alternately, if the class is on the larger side, then the amount of work per student will be reduced. In the end, this is all for the same six credits on the students’ transcripts, whether it is one tenth of the overall work or one twenty-fifth.

3.5 Institutional expectations, underclassmen and recruiting

A small program can leverage a high-profile project like FSAE in recruiting initiatives and to build excitement among underclass students. After a few years of doing this same project, it has become a topic of conversation among prospective students at recruiting open houses. A look at the old and (if available) current FSAE projects is a standard stop on the tour of the Mechanical Engineering facilities at York College of Pennsylvania. Many of these students then ask from early in their careers how they can help with the car project.
However, the use of FSAE as a Capstone Design project precludes extensive underclassman involvement. In order to provide as equal an opportunity for seniors participating in the FSAE project as a Capstone Design experience, faculty must actively discourage extensive participation by underclassmen. Otherwise, a small cadre of especially interested students may try to perform a large part of the design ahead of the start date for the first semester of the Capstone Design course, under the guise of “getting a head start.” This imbalance in the team could exclude some students from participating in critical design decisions and would preclude full participation of all team members in the design work. From an educational perspective, this is an unacceptable outcome.

Not all students are so keenly interested in the FSAE project, however. While the continued expectation of one day building a racecar inspires some students, it leaves other students disaffected. This becomes an issue when these less-excited students reach Capstone Design. In classes both large and small, these students tend to try to pass the course while doing as little as possible. This can effectively reduce the size of the project team and increase the unpredictability of the per-student workload from one year to the next, or one semester to the next. We have also observed that dramatic differences in enthusiasm for the project between team members can also lead to finger-pointing and resentment.

3.6 Competition versus education

The FSAE project quite clearly culminates in a competition with teams from other schools. The focus of the student team can then be shifted from the learning goals of the course to the vehicle’s performance at the competition. As evidence of this shift, students have, in the past, written fundraising materials focused not on how the project helps students learn via real-world engineering, but rather on anticipated placement at the FSAE event.

Like most of the issues in this section, the competitive aspect has both positive and negative sides. Some students are motivated by competition; the thought of trying to outdo other schools brings out the best engineering in these students. Also, the fact of the student team competing against other schools can help develop a sense of team cohesiveness. However, the competition places a great deal of stress on the team to complete the project as the deadline approaches. A portion of the students’ grade is tied to completion of the vehicle to motivate students. However, the stress this causes can also encourage particularly eager students to sacrifice too much time that ought to be invested in other important courses. The stress has built to a boiling point on some teams, causing arguments among team members and diminishing the value of the experience for some.

4.0 Student self-evaluation

As we have mentioned above, assessment and collection of data at a small program has certain challenges not seen at a larger institution. With classes of around twenty, it takes several years to collect statistically significant data. This means that the program at a small program is
naturally less likely to change projects quickly, since there is not enough data to tell whether a change is needed. Also, with a small sample size, an individual student has more of an effect on data collected or reported on a percentage basis. What we find from trying to assess the project at our small program is that we are forced to do the best we can with the data we are able to gather. An example of this is in the following subsection.

4.1 Student self-assessment of outcomes

To help determine the effectiveness of FSAE as a Capstone Design project, we administered an electronic survey to our alumni who participated in the project. This survey was offered via email to all 48 alumni of the Mechanical Engineering program that have participated in FSAE over the past three years. Six of the email addresses obtained from our alumni relations office were invalid, leaving a total pool of 42 potential respondents. 21 of these 42 have responded to the survey to date, reflecting 44% of the overall alumni population and 50% of the alumni with valid email addresses. The survey results are tabulated below.

Table 1: Results of alumni survey with a total of 21 responses.

<table>
<thead>
<tr>
<th>How much did your engineering design skills improve as a result of the FSAE project?</th>
<th>Much more than expected</th>
<th>More than expected</th>
<th>As expected</th>
<th>Less than expected</th>
<th>Much less than expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>9</td>
<td>8</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>How much did your teamwork skills improve as a result of the project?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>How much did your oral and/or written communication skills improve as a result of the project?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>13</td>
<td>4</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>How much more confident did you become in your ability to learn independently as a result of Capstone Design?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>10</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Overall, how much more confident did you become in your abilities as an engineer as a result of the project?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>10</td>
<td>2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>How well did FSAE meet your expectations for a Capstone Design project?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>8</td>
<td>6</td>
<td>3</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
Student comments about the project reinforce some of the known strengths of FSAE. Comments reflect highly on the experience of the competition, including the chance to network with representatives from the automotive industry. Student comments also note the improvement in soft engineering skills such as teamwork that resulted from the project. There were a few suggestions for improvement as well. One student noted a “disconnect” between what the competition requires students to do to compete successfully, and what the program is asking of the students, but the student did not cite specific examples so it is difficult to interpret this comment. Others asked that faculty find ways to get underclassmen involved, in the interest of improving the overall performance at the competition. This last thread of commentary highlights the difficulties students seem to have in separating competition from education within the FSAE project.

The survey results seem to indicate that students perceive most of the improvement in their abilities coming in teamwork and independent learning. The project increased almost all students’ perceptions of their own confidence. Perhaps most importantly, the student responses reflect that the FSAE project met their expectations for a Capstone Design experience, with 86% believing it met their expectations as well as expected or better. From the student side of the project, then, it appears that FSAE provides a good Capstone Design experience.

5.0 Conclusions

Given the goals for Capstone Design set out by the Mechanical Engineering program at York College of Pennsylvania, it is fair to say that FSAE is a good Capstone Design project with some challenging features. The technical rigor of the project is quite good, introducing design tasks from across the spectrum of the mechanical engineering field, and its administration by an external body removes the need for faculty to solicit design projects from colleagues and industry. The project can be implemented in a way that supports assessment of course outcomes, important for most small programs who seek ABET accreditation. The project also provides a conversation piece for the program, both for tours and for recruitment. Having a constant project in place gives students a goal to work toward in their careers, and allows them to start thinking about the vehicle, even if they cannot be allowed to design in depth before their Capstone Design course.

The areas where FSAE introduces challenges for a small program fall outside of its technical aspects. The competitive nature of the project requires effort by faculty to keep the educational goals as a focus of the project, especially as the competition date nears and tensions run higher than normal. The reports and presentations required by FSAE are not themselves sufficient for assessing student work (for accreditation and for grading), and require supplemental methods to be implemented, as we have done. The need to raise funds to build a prototype vehicle and to travel to the competition site can direct the students’ focus away from engineering and toward organizing small events to get money. Finally, the variations in class size combined with the
Immutability of the FSAE project makes it difficult to predict what amount of work a given student will need to do in order to earn a passing grade from one year to the next.

A small program can certainly implement this project successfully for a Capstone Design course. The faculty need to be aware, however, that the requirements of the course cannot solely be those set by FSAE if individual student work is to be appropriately graded and assessed. Also, faculty should be aware that all aspects of design and testing will not occur for the first few project iterations, but will come with time. Finally, faculty should try to identify funding sources in concert with students to give the students the opportunity to focus on the engineering work, which is what is desired for the Capstone Design experience in the first place.

Bibliography


