AC 2008-1391: A SNAPSHOT OF SUCCESS – HOW STUDENT-INITIATED AUTOMOTIVE DESIGN BECAME INTEGRATED INTO THE ME AND MET CURRICULA

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A Snapshot of Success – How Student-Initiated Automotive Design Became Integrated into the ME and MET Curricula

ABSTRACT

A fascinating relationship has evolved within our Mechanical and Industrial Engineering Department. Three years ago, students initiated the formation of a campus motor-sports club and formed an SAE chapter to pursue participation in the Formula SAE race series. Over the brief period since club inception, the activities of this group have transitioned into core elements of upper-division ME and MET coursework. The club has retained a significant portion of required fund-raising, as well as the responsibility for dictating vehicle specifications. The core of the student club-to-coursework relationship occurs in the interdisciplinary (ME and MET) Capstone Design course. Club-sponsored automotive design and build projects are treated essentially as any other industry-sponsored project, with the twist that they are funded primarily by students who are primarily enrolled in either the ME or MET curriculum. Many of the students fill dual roles: That is, they help define the projects in their role as club members and are then enlisted by course instructors to design/build/test the components as members of the design teams working, resulting in a course grade. This scenario has resulted in a level of student involvement in – and enthusiasm for – the engineering education process that has rarely been seen before at this university. Students are absolutely engaged in a broad spectrum of their education: They define the project, specify technical elements, raise money for materials & purchased components, design, fabricate and test. Then as club members they race the vehicles produced for recreation and enjoyment. Initially the interactions between club and ME/MET courses occurred through the inter-disciplinary capstone design course, but this activity has grown to involve courses in advanced instrumentation, composite materials, tooling, advanced CAD, and other coursework. This paper describes the present state of our Formula SAE race car project, the interactions between the student SAE club and the ME/MET courses participating in the relationship, and the path taken to arrive here. Positive and negative aspects of the relationship between the student club and required coursework are examined, and some guidelines and recommendations for the future are shared.

Montana State University Mechanical and Industrial Engineering

The Mechanical and Industrial Engineering (M&IE) Department at Montana State University (MSU) is among the largest departments on the 12,000+ student campus. The 600+ student M&IE Department houses three ABET-accredited four-year undergraduate degree programs: Mechanical Engineering (ME), Mechanical Engineering Technology (MET), and Industrial Engineering (IE.) Each independent program has dedicated faculty with shared administration and office staff. Course sequencing is organized per individual program goals and accreditation requirements, with some cross-disciplinary offerings available as elective or required courses.

The launch of SAE Formula Racing at Montana State

Engineering students at MSU have long been encouraged by faculty to investigate membership and participation in student chapters of professional organizations such as ASME. Membership in these organizations is and promoted in classes due to the well-known benefits associated with membership, in addition to the opportunities for learning that become available to student members. However, the initial setup and management of student chapters of professional organizations at MSU had always been in the hands of faculty. That changed in 2003, when several Mechanical Engineering students interested in automotive applications and racing met independently to discuss their desire to design, build and race an SAE Formula car in the annual SAE competition.

After some initial discussions, a small but enthusiastic core group of founding students approached this author with a request to act as mentor and faculty advisor for their newly-formed group. An agreement was reached to facilitate the founding of the club as advisor, but initially a hands-off approach to activities was taken while attempting to gage the likelihood of success of this group and to take time to investigate the setup of the SAE Formula Series competition. The group meanwhile registered with the university's student activities office to achieve approval as a registered student club, and initial meetings commenced in the rented garage of one of the students. The group elected officers to provide some club organization and also worked to become familiar with the extensive rule book posted on the SAE website.

One of the obvious first steps was to obtain funding for club activities: Fund-raising efforts were planned and students began to prepare flyers to distribute to local business. Cash was in very short supply when the College of Engineering at MSU stepped up with an agreement to provide a $20K startup package over a three-year "incubation" period, negating the need for extensive initial fund-raising. This step simplified first-year efforts and carried over through the following two years, providing essential resources to the effort. Flush with funds, the club members located and ordered a suitable Kawasaki 600cc engine and wiring harness from a Texas dismantler, and began working up a design for a car frame.

Over the next several months as the student group attempted to make progress towards producing the first MSU SAE Formula car, several realities became apparent:

1. The group did not yet have the engineering skill-set or experience to design a competitive SAE formula car,
2. The group did not have the manufacturing expertise to fabricate high-quality parts,
3. Privately-owned tools and homeowner-quality shop equipment were insufficient to build what was designed,
4. Time demands on engineering students are great, and often take precedence over optional/recreational "club" activities.

Due primarily to these issues, the first-year effort faltered and minimal results were achieved.

MIE Coursework connection

It was clear to the faculty advisor and to the SAE club president that, despite the first-year efforts falling short, a possible path to success could be found by incorporating the SAE Formula Car design and fabrication into engineering coursework. Specifically the introducing the SAE Formula Car topic into the required capstone course sequence in both the ME and MET programs was proposed. Upon a thorough review of course objectives and outcomes for both capstone courses and with consideration of ABET accreditation requirements, the idea was presented to the greater student group. The perceived advantages included:

1. Student Capstone Design groups responsible for various aspects of SAE Formula Car design would be equipped with the necessary engineering design and analysis training, via the pre-requisite coursework structure already present in the ME and MET curricula.
2. The engineering design activities would be performed for grade by those students involved, not as an extracurricular activity.
3. The design groups would be guided by experienced MIE department faculty, and their progress monitored.
4. Incorporating the project into senior capstone design courses would gain the groups full access to the department machining and welding facilities for fabrication of high-resolution components.

It was recognized that there was a risk of alienating SAE club members who were underclassmen and not yet eligible to participate in Capstone design and fabrication efforts. It would be necessary to find activities for these underclassmen or they would become disenchanted and seek other activities. After much discussion, the SAE club officers agreed that the goal of producing a race car would likely succeed only by combining their goals with Capstone efforts, and that there were probably sufficient tasks that could hold the interest of younger club members until they too could participate as seniors.

ME/MET Capstone Course Organization, Interdisciplinary Design Teams.
The ME and MET capstone courses are each organized conventionally into a two-semester sequence. Each course is staffed by an instructor responsible for lectures and course organization. Both require student teams to apply a formal design process to solve open-ended engineering problems. Many projects are industry-sponsored, or sponsored by engineering faculty through their research projects. Faculty advisors are assigned from a pool of faculty members representing the appropriate program. The first semester subject matter emphasizes design process application, alternative creation and evaluation, analysis, and documentation culminating in a formal oral presentation. The second semester features prototyping and testing, culminating in a “Design Fair” exhibition of results.

In recent years, capstone course instructors from the two programs have collaborated to assign multi-disciplinary student teams to several appropriate projects. In the case the SAE project, the benefits expected from merging these two disciplines was very appealing: Combination of the more extensive analytical training of ME student participants with the applications and manufacturing focus of MET students seemed to increase the likelihood of project success, and in any case would more closely resemble the teaming approach favored by industry and recommended by the Department's Industrial Advisory Board. The two programs, while closely related, produce students with notably different skill-sets. This is due both to the unique program coursework featured in each program, and to the aptitudes of students drawn to each program. Project teams theoretically are equipped to draw upon the strengths of both groups.

This close relationship between ME and MET Capstone has usually resulted in projects beneficial to students, faculty and sponsors. However, many challenges are present. Some are primarily logistic in nature - e.g. difficulties in scheduling class meetings and in finding fabrication space for the relatively high-resolution prototypes. These have historically not "stopped the show" but sometimes require creative handling. Other issues include:

1. Making accommodations for different levels of formal design process training between ME and MET students.
2. Variations in evaluation and grading within a project team, based on the faculty advisor's and course instructor's discipline-specific student expectations.
3. Different levels of faculty familiarity with elements of the two programs, varying levels of faculty acceptance, and buy-in to the notion of combined project work.
4. Analytical training differs between the programs: ME students often dominate design and analysis tasks during the first semester. The MET program includes welding and machining training, so MET students often assume a greater fabrication role during the second semester. This workload and skills imbalance renders grading difficult and generates frustration among student team members.
5. Prototype fabrication questions involving the desired resolution of the resulting parts (rudimentary vs. complex) and the ability of all students to participate in fabrication effort.
6. Sponsor proprietary rights, nondisclosure agreements, patent issues, sponsor expectations, funding, budgeting, sponsor involvement, and other issues common to any sponsored project.

SAE Capstone Group Setup, Roles

Three interdisciplinary Capstone SAE teams were created by the MET Capstone instructor/SAE Advisor with concurrence of the ME Capstone instructor. One group of ME/MET student s would be responsible for the Power train including engine, transmission, differential, axles and drive system: Another group was to design and build the frame and body: The third group handled the Steering/Suspension/Braking elements.

During fall term, each of the three groups were populated by two to three MET students and two ME students, who were assigned to the project based on their preferences stated at the start of the term. Nearly all the group members were already involved in the SAE club, and were given preference on the SAE Capstone projects. Those students who were not already SAE members were required to join to meet the rules of the competition. Two new ME group members were added to each group at the beginning of the spring term. This group size increase came about as a result of the larger enrollment in the ME program that permits the year-long Capstone projects to begin in either fall or spring, as opposed to the MET program which has a Fall-only start. The new ME members would serve alongside the original group members and then provide the "brain trust" to carry lessons-learned into the subsequent fall term design cycle.

The SAE club – consisting of some of these same Capstone design group students along with other students from ME, MET, and other disciplines – took on the role of the industrial sponsor. As sponsor, the SAE club was responsible for funding, setting specifications, reviewing preliminary designs, and assisting with configuration decisions. Later, upon "delivery" of the completed prototype, the club would be responsible for cosmetic treatment and integration of some of the last-minute elements as well as testing, driver training, race preparation and logistics.

Facilities

MSU's MIE Department has extensive design and manufacturing capability, used extensively by all Capstone Design teams but critical to the SAE Formula car groups. A fully equipped computer-aided design lab with the latest CAD software is complemented by a large machine shop with a selection of hand tools, manually-operated machine tools, and CNC machines. An adjacent instructional welding laboratory provides metal joining capability. Access to these facilities was granted to the student SAE groups for fabrication, but finding a suitable location for the large frame jig and the long-term assembly process was not an easy matter. After several false starts in various locations throughout the engineering complex at MSU, it came down to intervention by the faculty advisor and 'squatter's rights' to claim and maintain sufficient floor space in the welding lab. The facilities and space concerns added even more realism to the project as students realized that they were not the only game in town.

Educational Component and Outcomes

From the instructor's points of view, educational goals and outcomes of both of the capstone courses aligned quite will with this arrangement. Difficult analytical treatments of specific problems in materials, vibration, heat transfer and dynamics were present, and of course the nature of the project meant that a high-resolution prototype was required. Inter-group collaboration was key, due to the multitude of interfaces present between frame, engine, suspension, braking, etc. The three design teams each struggled to handle optimization and interface concerns as they considered manufacturing methods, weight control, structural integrity, and function. Project management elements including

budgeting, make-or-buy, planning and scheduling, assembly sequencing were ever-present. Quality assurance was a concern both with purchased parts and fabricated components. In short, the SAE projects contained all the elements of a real-world engineering task – because that is exactly what it was!

Despite the near-perfect alignment of the SAE Formula Car projects with pedagogical goals, these were not easy projects to deal with as instructor, advisor, capstone group member, or SAE Club member. The stakes were very high and so were the emotions of the students involved. Funds from the sponsoring SAE Club's treasury had to be committed early on, resulting in a "no room for failure" stress level among the players. This stress was compounded during the manufacturing delays and errors typical of student projects. Club members were forced to step into a different role when after the end of the scholastic term some component assembly was still unfinished. The original core group of SAE founding students were among the individuals who stepped in to finalize the fabrication, help with travel arrangements, and finish the first-ever MSU SAE Formula racer.

First Success

The efforts described resulted in a fully functional race car that met SAE rules. The MSU vehicle and team earned a respectable 45th place overall out of 72 registered teams at the SAE Formula event in Fontana, CA. This was considered an excellent showing for a first-year team, and the result set the stage for evolution of this student-initiated project.

Second Year Evolution

Lessons learned from this first-year effort bolstered the second-year car. Design of this vehicle began in fall term 2006, and followed roughly the same procedure as year one. The two major differences were an increased responsibility for fundraising by the SAE Club since the initial COE funding was more than half expended, and the incorporation of SAE Formula topics in other MIE classes.

The presence of SAE Formula Car topics in an increasing number of courses was noteworthy: In addition to the Capstone courses in both ME and MET, students in advanced Computer-aided Design courses were permitted by their instructors to use car design elements as subjects for their required course projects. Students in the Composite Materials course produced designs for the composite fairing assemblies of the SAE car. The existing ME448 "Design of Tools" course incorporated projects related to fabrication of SAE Car components. And SAE students enrolled in the MET417 Advanced Machining course were encouraged to machine car parts for their class project.

The second-year car and SAE "Bobcat Motorsports" Formula car team competed in the second annual SAE Formula West competition in Fontana, CA in June 2007, and took home a 24th-place overall finish of 80 teams. The car was one of only 17 that successfully competed in every event, and scored in the top 10 in some events while competing against some of the worlds top engineering schools.

Upon return from the second year's event, it was apparent that the SAE Formula Car had reached a new level of success: The car was discussed in lectures in numerous other courses as well as touted on promotional brochures and university websites. It had become one of the centerpieces of MSU Engineering facility tours, and prospective students were guided to the fabrication area. News stories hit the MSU web pages and local newspapers, and the SAE Car project was a major recruiting tool. Anchors of the evening news highlighted the car project, interviewed SAE Club members, and took a spin in the parking lot with cameras rolling. Alumni wanted photos posed with the car, and the SAE Student organization had a record membership increase.

Third Year Status

Fall term 2007 again followed roughly the same ME/MET Capstone Design coursework model, with the exception that a fourth design team – Cockpit and Ergonomics – was added to spread the workload.

The club, having expended all funds provided by the college, set forth on a fundraising blitz. Cash and in-kind donations of nearly $50,000 had been realized by the end of Fall term 2007, enough to pay for components, travel and raw materials for the third-year vehicle with cash left over for future needs.

Even more courses began integrating the SAE Formula Car into the engineering subject matter: A new professional elective course, MET480 "Advanced Instrumentation and Control" was offer during fall term. The class project was the design and fabrication of on-board instrumentation system for the 2007 SAE Formula car. The course activities included steps of defining system architecture, specification of design/performance requirements, component selection, data acquisition system programming, and integration of the resulting prototype into the existing vehicle. The existing ME448 "Design of Tools" course proposed incorporating a major design project to create a welding fixture for the frame. And the Composites course had design projects to utilize advanced materials for fabrication of the seat, fairings, and other structural elements of the car. The Advanced Computer-Aided Design course will again incorporate SAE Formula Car subjects among the project work utilized in the class, and students in the Advanced Machining class will fabricate a number of complex components for the 2008 car. Students from Computer Science (CS) at MSU have gotten involved, and are programming graphical user interfaces as a CS Capstone project.

SAE Formula Mainstreamed in MSU Engineering

The relationship between a student project and engineering coursework that has developed over the short time period described is relatively complex, but workable. Students have enthusiastically taken charge of a portion of their own education: They are engaged in the topic, the funding, the design, fabrication, test and final evaluation in terms of the annual Formula SAE Competition. Montana State University engineering students have truly taken ownership of their own learning.

In retrospect, the transition and evolution has been spectacular. The activities that began with a few MSU undergraduate students have - in just over three years - evolved into mainstream elements of several upper-division MSU Engineering classes, involving many dozen students and influencing hundreds. The SAE Student chapter members now raise funds that supplement and support their own educational expenses that are incurred in multiple courses – a situation that is unprecedented at this University. College and Department administrators have recognized the benefits of this development, so that now the Department of Mechanical and Industrial Engineering and the College of Engineering both rely heavily on these student-initiated activities to promote the engineering curriculum to prospective students.

The SAE student chapter and Bobcat Motorsports club continues to grow and attract new members from engineering disciplines and from across campus. It continues to be a remarkable story.