Session 2793

Center for Advanced Manufacturing and Production: Enhancing Engineering EducationThrough Team-based Multidisciplinary Projects

Michael J. Batchelder, Electrical and Computer Engineering Department
Daniel F. Dolan, Mechanical Engineering Department
Sriniviasa L. Iyer, Civil and Environmental Engineering Department
South Dakota School of Mines and Technology

Abstract

The role of engineers has changed in recent years from solitary designers in the laboratory to members of teams that have to sell their ideas and work with customers. Engineering education is changing to meet the needs of the changing role of engineers. In response to these changes, the goal of the Center for Advanced Manufacturing and Production (CAMP) is to improve the education of undergraduate engineering students through team-based multidisciplinary projects. CAMP focuses on combining the individual student's discipline expertise with the multidisciplinary team requirements in design and manufacture of a complex product. Realistic projects large enough to require teams provide the basis for experiential learning in communication skills, teamwork, and leadership abilities. Engineering students with at least a 3.0 GPA or special expertise are invited to join CAMP as juniors. In addition to taking required courses in manufacturing, multidisciplinary design, business, and networking, the CAMP students become leaders in multidisciplinary team projects as they progress through the program. CAMP contributes to the improvement of undergraduate education by involving students in challenging projects in competition with engineering students from across the country. "National norming" is an important part of CAMP -- students compete in national engineering contests. The centerpiece CAMP projects are Sunrayce, SAE Mini-Baja, and Formula SAE Mini-Indy races. The teams are responsible for not only design and manufacturing, but also fund raising, publicity, and finding sponsors -- skills that readily translate into their profession when they graduate. Industry sponsored projects are also part of CAMP. Projects appropriate to the academic calendar and student abilities provide experience for CAMP students and an aid to industry. The three faculty co-directors work with six graduate students and a dozen undergraduates who are managers and mentors for 33 CAMP student leaders who in turn lead multidisciplinary projects which involve approximately 100 students. Since many of these projects are connected with courses, approximately 400 students are indirectly affected.

Introduction

The role of engineers has changed in recent years from solitary designers in the laboratory to members of teams that have to sell their ideas and work with customers. Engineering education is changing to meet these changed needs; however, teaching effective teamwork is difficult. *"Teamwork: industry wants it and ABET 2000 requires it. But effectively implementing and managing student groups for class projects, lab work and presentations is a complex affair, one* *that requires organization, understanding, and tact."* [1] The Center for Advanced Manufacturing and Production (CAMP) was formed to develop students able to excel in multidisciplinary teams, using industry sponsored projects and national engineering competitions as a means to grow these skills. *"…the use of competition as an approach to teaching design is an excellent experience for those involved, in that it gives students experience with teamwork and introduces them to practical problem solving situations. It also seems to bring out their best technically."* [2]

Focusing engineering education on projects and competitions is a popular approach to giving students experience with real open-ended design problems, teamwork, communication, and leadership. To help motivate students, projects often involve competitions (local or national) or are sought from industry. Examples of competitions range from a number of robotic contests [3, 4, 5, 6, 7, 8, 9] to solar powered boats [11], to solar car racing [12, 13, 14],to aerial robotics [15], to Indy style racing (SAE Mini-Indy), to off-road racing (SAE Mini-Baja), to concrete canoes.

In Criterion Three of EC2000, ABET requires that engineering programs demonstrate that their graduates have fundamental knowledge and know how to apply it working in teams while considering the ethical and societal context of their designs. Student teams competing in contests develop not only technical skills, but also communication and teaming skills. Typically, student teams must seek donations of components, supplies, equipment, and money thus developing presentation and sales skills. Vehicle competitions, such as Sunrayce, Formula SAE Mini-Indy, and SAE Mini-Baja, have a strong emphasis on safety leading students to understand their designs in terms of a broader context. All contests have rules. This forces students to consider their interpretation. (Is it ethical during a solar car race to purposely force another team to be stopped by a red light?) Cooley et. al.[2] provide a good discussion of the advantages of competitions in teaching design.

Vision of CAMP

The vision of CAMP is to integrate students, faculty, and industry partners into a Center that provides a unique approach to engineering education. Modeling the multi-disciplinary, team-based philosophy to which we are committed, CAMP is directed by Dr. Michael Batchelder (ECE), Executive Director, Dr. Dan Dolan (ME), Academic Director, and Dr. Srinivasa Iyer (CEE), Industry Director.

SDSM&T had participated in the national engineering contests for many years before CAMP was formed in October of 1997. By combining the teams within the CAMP structure and striving for specific educational and professional outcomes, we have seen greater returns from the efforts invested. Faculty mentors working with CAMP team leaders are able to coordinate projects more efficiently and effectively. Non-technical aspects of projects tend to be the issues that keep groups from working smoothly and projects from being successful[16]. Teams need to understand the importance of team dynamics and the value of conflict[17]. Weekly seminars prepare CAMP students for leadership positions including lectures on project management, instruction on teaming from faculty members in psychology, motivation talks from athletic coaches, and teaming workshops.

Figure One illustrates how the effort of a few faculty members, with graduate student support, can multiply their effectiveness through trained student leaders. CAMP projects are vertically integrated, freshman through senior students, with the addition of graduate student and faculty mentors. This provides freshman and sophomore students the opportunities to mix with junior and senior students, absorbing skills and attitudes which benefit their studies in engineering classes. Students not involved in CAMP projects are indirectly affected by use of homework and lab assignments related to CAMP projects.

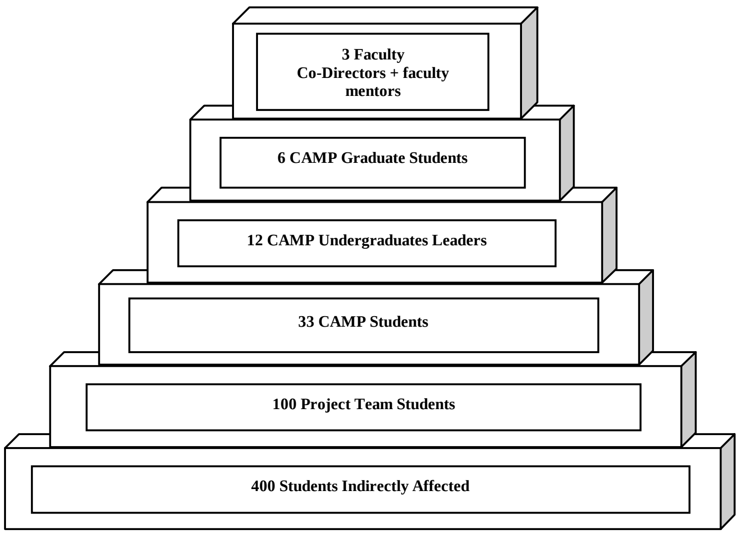

Figure One. CAMP Organizational Structure

CAMP Student Members

CAMP is a type of honors program - incoming juniors can apply to become CAMP students and are selected based on grade point average (3.0 or higher) or evidence of special expertise. As CAMP members, they use the elective credits from their degree majors to fulfill CAMP course requirements in manufacturing, business, networking, and multidisciplinary design. They also attend weekly seminars on communications, teaming, project management, and leadership. As part of their education, students participate in enterprise teams centered on industry-sponsored projects or competition projects. Teams consist of students at all levels, from freshmen through graduate students, together with faculty and industry partners and are open to students from all disciplines. As CAMP students gain experience, they qualify to be team leaders. Project work is coordinated with designated CAMP courses.

All work on the projects is done in student teams. The student leaders are CAMP members, and team members join to gain engineering experience on real projects. They can receive credit for their project work in capstone design courses or design courses as part of the normal curriculum. Freshman courses through graduate courses have incorporated aspects of the CAMP projects into homework and laboratory assignments. The skills the students gain from the experience on the actual engineering projects fit quite well with the requirements of Criterion Three of EC2000.

CAMP Projects

Three ongoing vehicle competition projects - the solar car, the Mini Baja, and the Mini-Indy - were chosen as primary CAMP projects to provide a training ground for students. These were chosen both for their potential for involving a wide spectrum of disciplines and for the external measures of success that the corresponding national competitions provide. Additional competition projects that CAMP supports include the Concrete Canoe, the Human Powered Vehicle, and the IEEE Robotics contests. External projects give more advanced students an opportunity to interact on industry sponsored projects while providing aid to local industry.

Significant Improvements to Engineering Education

"National norming" in national collegiate engineering contests keeps project standards high and simulates industry setting of achieving goals with limited time and resources against strong competitors.

The structure of CAMP allows a small number of mentors to have the opportunity to develop desired attributes in a large number of students through a substantial engineering project.

Students are generally well prepared technically. Projects falter and fall short of their potential due to non-technical issues. Most students major in engineering because they are interested in designing, building, and testing. They do not enjoy documentation, developing (and sticking with) schedules, and being required to coordinate with other groups; however, these are the skills ABET and industry want developed. Work on significant projects soon shows the importance of developing these abilities.

Tradeoffs always occur when such a program is introduced. There is criticism that technical capability will decline. It appears that exactly the opposite occurs; students actually learn the fundamentals better when they see the need for such understanding in their project work. The students strive for the excellence that develops when the experts do the job and lose the mediocrity that occurs when students work out of their disciplines. The arrogance of separate department activity gives way to the positive humility of teaming, and boredom gives way to excitement.

Results

The goal is producing students able to excel in multidisciplinary teams; thus students do all the design, fabrication, testing, and management of the projects. Instead of making winning the competitions the first priority, education is paramount with the competition providing a strong motivation. A summary of the results for 1999 national competitions are given below: (more details can be found in the attached appendices and on the CAMP and student team web sites [18, 19, 20, 21, 22].)

- 25th out of 29 in Sunrayce99 (only 29 of 54 teams qualified for the race),
- 30th out of 72 in Mini-Baja,
- 42nd out of 100 in Mini-Indy,

- 5th out of 250 in Concrete Canoe,
- 7th in Human Powered Vehicle,
- 3rd in IEEE Robotics Region 5.

Industry projects are based on the same approach of students doing all the work with faculty involved primarily as mentors and consultants. Industry projects in 1999 include:

- Oil/water separation for the restaurant industry to reduce effluents,
- Galvanized steel joists for floor and roof support,
- Jewelry manufacturing using parametric modeling CAD tools,
- Durability testing of an after-market air suspension system for Harley Davidson's soft-tail "Hog".

Administrative support has been important in meeting CAMP goals. *"Among the most important things we can take with us through life from our formal education are a joy in learning and a thirst for more. As I talk with the students and faculty involved in CAMP, I find a level of enthusiasm and feeling of mutual respect and shared enterprise from both I have seldom encountered. This itself tells me the CAMP approach is the right one to prepare students for a lifetime of learning. It is an exciting way to learn; it is an exciting way to teach."* (Dr. Karen Whitehead, Vice President SDSM&T).

Students are enthusiastic.

- *"A flipped sign doesn't cut it. The answer in the back of the book doesn't exist. CAMP is an exciting workshop for real-life engineering where there are no hard and concrete answers. The 100% hands-on, practical projects that CAMP oversees are where many students like myself connect the theoretical with the practical and have a lot of fun at the same time."* (from a current CAMP student)
- *"The benefits of CAMP went far beyond being just another line on my resume. It gave me another opportuinty to interact with other engineers and begin the networking process that aids in realizing lifetime goals. As a practicing engineer working within sales and middle management, I see such networking practices as being absolutely necessary to gain success both personally and in business" (from a graduate of the CAMP program)*

Industry support for the concept has been strong. The University Advisory Board (composed of executives of major engineering companies), the CAMP Advisory Board, individual department advisory boards, and recruiter feedback have all given positive feedback. As a tangible vote of confidence in the goals of CAMP, Caterpillar has recently made a significant donation to SDSM&T to construct a building to house the CAMP student projects.

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19. Solar Car Team URL: http://www.sdsmt.edu/student-orgs/solar/

20. IEEE Robotics Team URL: http://ieee.sdsmt.edu/

21. Mini-Baja Team URL: http://www.sdsmt.edu/student-orgs/sae/baja/

22. Mini-Indy Team URL: http://www.sdsmt.edu/student-orgs/sae/fsae/

Biographical Information

MICHAEL J. BATCHELDER
Mike Batchelder joined the SDSM&T faculty in 1974 after completing a Ph.D. in Electrical Engineering from Virginia Polytechnic Institute and working in industry for several years. Mike, a professor in the Electrical and Computer Engineering Department, has enjoyed teaching undergraduate courses for almost 25 years. In addition, he has experience with administrative duties as past chair and interim dean and has worked with the South Dakota Governor's Office of Economic Development on many projects including two startup companies. His interests include the hardware and software of embedded computer systems.

DANIEL F. DOLAN
Dan Dolan joined the faculty of the SDSM&T in 1981 after completing a PhD in Mechanical Engineering from the University of Minnesota and a Post Doctoral Fellowship at the University of Duisburg in Germany. He has been actively involved in the teaching of undergraduate courses for almost 18 years. He has taught courses in thermodynamics, dynamics, controls and manufacturing. He enjoys teaching in all of these areas, but especially in vehicle development courses such as *IC Engines* and *Vehicle Dynamics*. He has worked in industry for General Motors and Onan on engine development and at MTS on manufacturing control system development. He has co-authored over 25 technical papers and is the co-inventor on two patents.

SRINIVASA L. IYER
Srinivasa L. Iyer joined the faculty at SDSM&T after completing his Ph.D. at SDSM&T in 1974. Prior to joining SDSM&T, Dr. Iyer had 14 years of experience in teaching and industry. He has taught undergraduate and graduate courses for nearly 38 years. Recently he was responsible for establishing the Advanced Composite Lab at SDSM&T. He has received two US patents and he is a member of several professional organizations. He served as Director of Economical Development at the State level for seven years and administered several industrial projects. Dr. Iyer serves the university as its Patent Officer. His interest is in product development and research in the area of advanced composites such as carbon and fiberglass.

Appendix One   Concrete Canoe

Figure A1.CAD/CAM designed and machined frames for the Concrete Canoe mold.

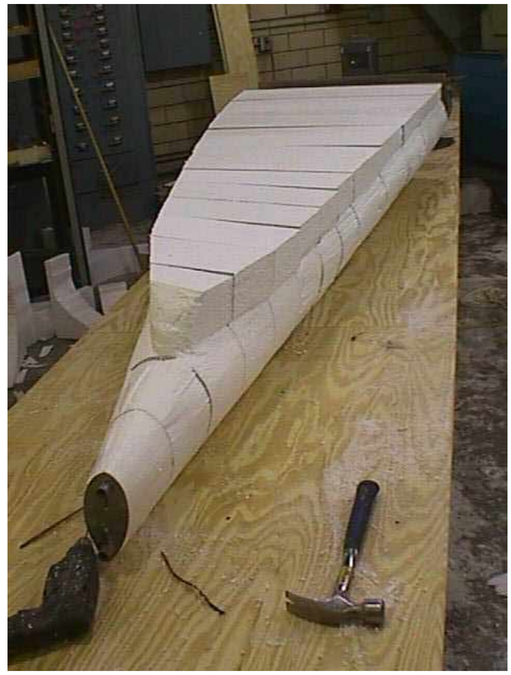

Figure A2. Concrete Canoe mold of Styrofoam taking shape.

Figure A3. Completed Concrete Canoe that placed first regionally and 5th nationally.

Appendix Two Society of Automotive Engineers Mini-Baja Competition

Figure A4. In the 1998 SAE Mini-Baja competition, the SDSM&T team won first place in the Sales Presentation, ninth place overall, ninth place in the Acceleration test, eleventh place in the Maneuverability Test, and sixteenth in the Endurance Race.

Figure A5. In 1999, our students placed in the top ten in five out of the seven events of the competition: 4th in the Hill Climb event, 6th in Safety and Design, 8th in Maneuverability, 9th in Sales presentation, 9th in Acceleration, 42nd in Cost, and 48th in endurance (due to a broken axle) which put them at 30th overall. The picture shows Dan Dolan helping with adjustments during development.

Appendix Three Formula SAE

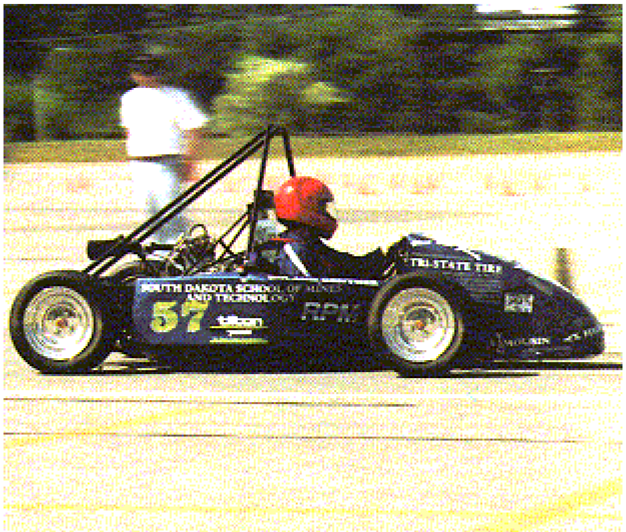

Figure A6. Formula SAE Mini-Indy.
Students use parametric solid modeling (Solidworks) and an array of analysis tools including FEM (Algor) and 3D dynamics modeling (Working Model 3D) to design this small formula-style race car. Components are manufactured using Mastercam and CNC machine tools, the frame is welded, a fiberglass body is made and the car is assembled. Following a significant test program the students travel to Pontiac, Michigan to compete against about 100 other teams. The 1999 standing was 42nd.

Figure A7. The solar car team designed a composite chassis of E-glass fiber wound on aluminum honeycomb. This picture shows the chassis being wound on the composite winding machine.

Figure A8. Cured chassis after removing from mandrel before bulkheads are installed. The roll bar is being test-fit.

Figure A9. Styrofoam shell during construction. One pound density foam blocks are glued together then cut to shape with a hot wire

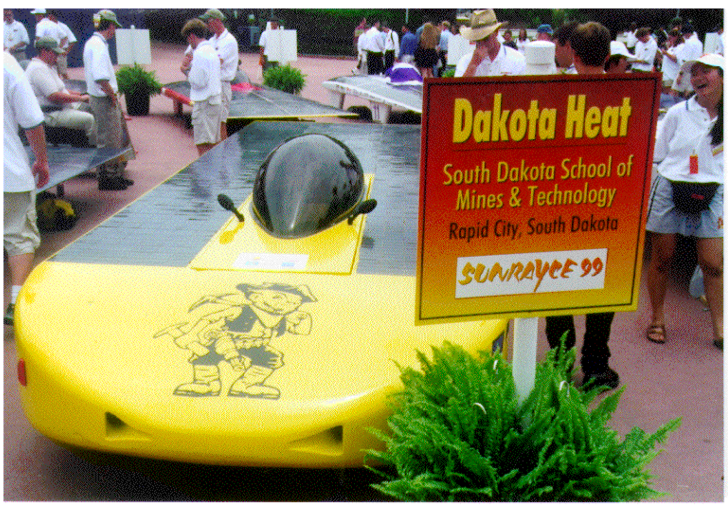

Figure A10. Solar car after completing Sunrace 99, a race from Washington D.C. to Epcot Center in Orlando, Florida. Of the 54 teams planning to participate, only 29 qualified for the race. Our entry finished in 25th position.