2007: CRITICAL ISSUES ASSOCIATED WITH AN INDUSTRIALLY SUPPORTED CAPSTONE DESIGN PROGRAM

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Abstract

Senior level capstone design courses are run in many different ways in the academic community. A growing number of institutions strive to promote immersion into the real world of engineering through industrially sponsored projects. While this approach offers many immediate benefits to near-graduating seniors, it introduces many unique problems to the academic community. Developing and sustaining an industrially-sponsored capstone design program requires an understanding of the synergies and differences between academia and industry. Key issues that are addressed in this paper are why a company would sponsor such a program, how does industry allocate funds to sponsor such a program and what level of involvement is required to make a successful project and what are the legal implications of sponsoring a meaningful project.

Introduction

Senior level capstone design courses are run in many different ways in the academic community. Many institutions have programs based on developing a single product entity, like an SAE or mini-Baja vehicle[1]. Small student teams work on individual vehicle components, but the goal is to complete a single entity for some series of trials at the end of the program. Other institutions do not require the development of a working model; rather their goal is a paper design study, e.g. an airplane or a model manufacturing plant. Some institutions have their students work at developing new experiments to support their academic program, thereby modernizing their thermal-fluids and dynamics laboratory experiments on a regular basis. In contrast to these approaches, a growing number of institutions strive to promote immersion into the real world of engineering through industrially sponsored projects. While this approach offers many immediate benefits to near-graduating seniors, it introduces many unique problems to the academic community.

Over the past seven years, the University of Connecticut (UConn) Mechanical Engineering's industrially sponsored capstone design program has grown from 22 students to 90 students[2]. Experience has shown that teams larger than 2-3 do not work effectively, that is all members do not contribute equally to the project's goals. Over this time period, the number of sponsored projects has grown from nine to more than thirty. Each project team is supported by a single faculty advisor, with no exception. Since the number of teams has already exceeded the size of the faculty, individual faculty members have volunteered to advise more than one team. Projects are solicited from local industrial companies, asking for a supporting grant to run the program and up to $2000 to cover specific project costs. Some project costs have substantially exceeded this amount, i.e. $5000 to $25,000, but always depending on sponsor prior approval of a ROM budget.

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The primary objective of this paper is to discuss the unique issues of generating industrial support[3], the legal issues arising from such a program, the burden of project diversity and professionalism issues, as directly experienced by the Mechanical Engineering department at the University of Connecticut.

Generating Industrial Support

Developing and sustaining an industrially-sponsored capstone design program requires an understanding of the synergies and differences between academia and industry. Academia needs to foster a symbiotic relationship, rather than a parasitic relationship with industry. First of all, academia needs to rid itself of the perception that industry has plenty of discretionary funds to support university initiatives. Typically, there are three sources of industrial funds that can be tapped for university purposes: discretionary, overhead and engineering R&D budgets. The first two categories tend to be small and committed substantially before the start of the academic year. The latter is most easily accessed, but one must recognize that for-profit companies can and do contribute to academic organizations, but the supported research or technical services need to fit within a company's goals.

A related issue is that the academic year is not aligned to the industrial fiscal year. Companies approached during the summer frequently do not have available uncommitted funds at this time of the year. At UConn, companies are normally billed early in the academic year for their sponsorship fee, and at the end of the academic year for the project costs incurred by their team. The fee is treated is a grant, not as a specific task order contract. University billing however can require a degree of billing flexibility, allowing sponsors to make a late payment of their fee after the start of their next fiscal year (Spring semester) or to be billed for early payment of project cost, before the end of the fiscal year using end-of-the-year money (Fall semester). Academia has to adapt to what is more advantageous to the sponsor.

A second issue is the recognition of why a company would sponsor such a program. If the projects are of real-world interest, then one should expect that only a fraction of the *student* projects will result in practical or usable products. The primary reason for sponsorship is to gain access to the best of the graduating senior class to fulfill hiring requirements. Some sponsors are now actively integrating their junior year coops – internships into funded capstone design projects, thereby getting extended opportunity for assessing future hires. Successful projects require a strong commitment from the students, their faculty advisors and the sponsor mentors. Satisfied sponsors typically recommit from year to year, but business pressures and mentor availability has prevented several sponsors from "reupping."

A third issue is consideration of what makes a successful project. The key elements that contribute to this are a well thought out problem, commitment of the company mentor to supporting the team, good students and a good faculty advisor. A company mentor rarely gets excused from his or her daily work commitments, but has to support the team as an unfunded *pro bono* initiative. The students and faculty must realize this from the start of

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the project. It is hard to define what student capabilities are necessary for a good design team. While important, GPA is not a guarantee. People skills, initiative, creativity, etc. tend to be more important traits, but are harder to measure. None of these are known when a team is formed. The students are given the projects to be worked during the first day of class of the coming academic year. Students are asked to select their 1st to 5th choice and whom they would want as teammates. These requests are balanced by the class instructor only with the student's GPA as a metric of academic competence, not especially true whether they would be a good designer. To improve the functionality of the group, personality evaluations are being made early in the fall semester using the Myers-Briggs TI [MBTI][7,8] to try to correlate team performance with personality type and trait.

A final issue for state universities is the concern of private industry regarding any ethical impropriety regarding sponsorship grants. Many industrial companies are registered lobbyists to the state government. Task-order contracts between state universities and private companies do not represent a problem, but grant funding may be construed as an unethical business practice. For practical purposes, the grant request has to be loosely worded and has similarities to the U.S. Army's *don't ask-don't tell* policy. The funding interpretation is a moving target and changes from year-to-year.

Project diversity

Many U.S. engineering schools have moved towards a 128 credit degree requirement. This is driven by concerns of economic competitiveness and an effort to keep the engineering degree to 4 – 4.5 years in length. This results in seniors having little depth beyond the basic ME curriculum. Such a narrowly focused education can represent a challenge to capstone design students, where the local sponsoring companies technical and applications are extremely diverse. At UConn, while the big aerospace / defense industries are big supporters of the program, local sponsors specialize in computer chip lithography, elevator design, production of personal care products, and development of surgical products, see Table 1. Although the projects tend to fall into general categories: thermal-fluid controlled problems, applied mechanics controlled problems, and manufacturing process or product development, the sophistication and depth of these problems is typically beyond the students academic training at the onset of the program. This requires the students to become rapidly knowledgeable in software, hardware and physical concepts not part of their "four-year" education. For example, many teams had to develop expertise in advanced CFD or FEA software, become knowledgeable in advanced sensor techniques, learn to use nontraditional materials, and develop devices for extreme environmental conditions [thermal, humidity, radiation, etc.].While this serves to reinforce the ABET criterion [3i] of "the need for life long learning," it puts a strong burden on students carrying four or more academic courses. The diversity of projects and corresponding required technical disciplines even stretches finding knowledgeable faculty advisors for the many disparate teams.

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Table 1. 2006-2007 Industrially Sponsored Capstone Projects

Sponsor	Title
ASML	Active Faceted Mirror Array for Use in Extreme UV Lithography
ASML	Lens Purge Efficiency Parameter Study of Multiple Variables
Pratt&Whitney	Gas Turbine Rotor Disk Systhesis
Pratt&Whitney	Design and Validation of S-duct Inlets at Static Condtions
Henkel-Loctite	Real Time Measuring and Monitoring of Adhesive Flow
Henkel-Loctite	Pre-Activated Epoxy Dispenser Designs
MTU Aero Engines	Improvement of Deburr Procedures
Hamilton-Sundtrand	Space Vehicle Air Velocity Distribution-Design & Prediction
Gentex	Eng. Development Platform for Injection Cooling of Optical Lenses
Otis Elevator	Bearing vibration Insulation Kit Design, Manuf. And Characterization
Pharmacy	Pharmaceutical Grinding
Unilever	Late Variant Addition System
Unilever	Design of a Hairspray Manufacturing System
UTCPower	Fuel Cell Plant Frame Enclosure
Jacobs Vehicle Systems	Bleeder & Exhaust Brake Modeling & Calibration
Electric Boat	Sub LITE Submarine Low Impact Tether
Capewell	Core Material Redesign of HCU-6E Military Pallet
OSIM	Reverse Eng. Of the Isqueez Foot Massager System & Design Changes
OSIM	Hinge System Design
OSIM	iGallop Efficacy Study & Reverse Eng. & Design Imp.
OSIM	GUI-Based Massage Chair Interface
Carlyle-Johnson Machine Co.	No-Bak Brake
GKN Structures	Electric Pin Installer & Pneumatic Pin Remover
Pitney Bowes	Reliable Hub-Shaft Joint for Mail Processing Products
Wiremold-Legrand	Enhancing Security Features on Current Raceway Systems
Sikorsky	Sensor Design To Measure Distance Between Counter-Rotating Blades
Fuel Cell Energy	Environmental Chamber for PEM Fuel Cell Membrane Characterization
Pioneer Aerospace	Performance Capability of Various Parachute Designs with CFD
Siemon Co.	Automated Inline Connecting Block Vision Systems
Dental	Fatigue Life of Titanium Dental Implants

Another aspect of project diversity arises in how industry defines what constitutes a design project. An ideal design project involves brainstorming, concept selection, detailed design prototyping, etc[4]. Many projects of a mechanical nature follow this classical design paradigm. For thermal-fluid, applied mechanics, and material processing driven projects, the goal may not be a mechanical design, but to develop concepts that lead to either improved design concepts or processes. In industry, this is seen in terms of efforts to reduce that amount of testing as a means to reduce design time and development cost. Therefore, industrially defined projects may have a larger mechanical or analytical / computational element. This makes it hard to compare the design efforts of the individual teams. Sometimes mechanical components are constructed by encouraging analysis-oriented teams to develop experiments to verify their concepts. Finally, any fabrication of design of test equipment must be performed largely by students. While some sponsors volunteer to do all production / fabrication, problems have arisen where sponsor product commitments [in the last minute] do not permit this to occur. Therefore, ALL students are required to complete a shop-training – safety program that will permit them to use the university shop facilities to fabricate their designs or necessary experimental equipment. Several representative examples of the breadth of recent industrial projects are given below.

Geometry Effect on Air Gauge Measurement Sensitivity: ASML, a company that develops lithography machines to etch blank silicon wafer into a computer chip, uses air gauges to accurately measure distances on the order of 100 microns. The air gage senses the backpressure exerted when a jet of air is shot through a nozzle perpendicular to the specimens surface. In response to ASML's request, the students developed a more sensitive air gauge to compensate for the growing demand for improved computer chip performance. Through an optimization of various geometric features, an improved air gage design achieved higher measurement capabilities. The student team became proficient in Fluent CFD software use and learned how to interpret the predicted results. The CFD studies were used to evaluate design concepts and geometrical modifications. Analytical models were developed as limiting forms of the Navier-Stokes equations and used to explain the dominant physical mechanisms observed in their CFD predictions. An experimental setup was developed and used to validate the computational model for the base nozzle and the improvements predicted for the new nozzle design.

Automated Thrust Bearing Hydraulic Lift System: Westinghouse Electric, a developer of nuclear power plants, uses reactor coolant pumps to supply water to the reactor core via reactor coolant pumps. Within each of their four reactor coolant pumps is a thrust bearing that controls any damaging thrust or lateral forces created in the motor shaft between the motor and spindle. To perform regularly required maintenance, the thrust bearing assembly, weighing approximately 17,000 pounds, must be lifted vertically approximately 13 inches from its bottom-mating flange. Also, the thrust bearing has to be lifted at a tolerance of 0.042 degrees from initial level for the entire lift.

The student-designed system utilized hydraulic modules to support requirements for complete system portability. To allow the operator to transport the entire system throughout any terrain, each system module is designed to be carried like a briefcase and weighs less than 50 lbm each. A dual-axis inclinometer and a laser distance sensor were used to continuously measure tilt and height displacement. Pressure transducers were also utilized for each of the four hydraulic actuators in order to monitor the force at all points of lift. All sensory devices operated within extremely small tolerances in order to keep the thrust bearing parallel with its mating flange at all times. Upon command via the operator's modular control panel, the control system utilized Proportional Integral Derivative (PID) microcontroller technology to successfully perform the required lifting regimen and diagnostics. The final system also had to be capable of operating in a low radiation environment without any degradation of capability over time.

Pressurized Thrust Bearing Test Stand: Electric Boat Corporation [EB] is developing a prototype surface vessel rim-driven propulsion systems to be employed on sub-surface vessels. EB presently uses a commercial software program to develop thrust bearings and predict performance. The program has been used to design a bearing, which will be exposed to the high ambient pressures encountered at great depths. Predicted performance must be validated from scale model testing. The student team developed a rig to rotate a thrust bearing runner at high speeds up to 1,700 rpm, while maintaining the bearing in a sea water environment pressurized at up 500 psig. Critical issues of seal design and selection under a high-pressure, high-RPM, saline environment were successfully addressed. The apparatus measures the torque imparted to the bearing mount in the range of oz.-in. and axial loads of up to 600 lbf. Tests have been conducted compared favorably to scale model results to EB's software predictions. The test stand is currently in use at the Electric Boat facility.

Legal Issues

Industrially sponsored capstone projects introduce both the students and faculty to the current, constantly changing world of engineering. Protection of competitive information is critical today, as much as scientific details were protected during the Cold War. Protection arises from either gaining access to competitive information or from releasing information that would eliminate any competitive advantage for the sponsor. Most industrial sponsors require student teams and involved faculty to sign Non Disclosure Agreements [NDA]. The sponsor must inform the students and faculty what information is proprietary and what should not be publicly disclosed. This represents a difficulty for all student oral presentations, which are in a public forum format as well as for the end of the year "Demonstration Day" event in which the students showcase the results of their design efforts.

A more difficult concern is the issue of Intellectual Property [IP]. A real world industrial project always has the potential for real IP. In the working world, most companies require employees to sign an agreement relinquishing all rights to ideas, devices, concepts developed while an employee of the firm. The senior design team members however are not employees of the sponsor or of the university in which they are enrolled. The faculty advisors are obviously employees of the university. Therefore, the issue needs to be treated separately from the sponsor side, from the student team side and from the faculty side. First, the sponsor is encouraged / asked to internally document prior to project initiation, any ideas, concepts, etc. that they feel may lead to patentable or protectable material. Next, the students are encouraged to sign over any IP rights, as any employee or contractor would. The sponsor is also made to realize that any effort to prosecute a patent based on the students work is complicated by the fact that they will

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typically be unavailable to support such an effort after their graduation. With some difficulty, three industrially supported project have resulted in a patent filings with the students included as coauthors.

As an aside, a professional patent attorney introduces the students to the various aspects of IP through a formal lecture. The attorney describes the differences between trade secrets, trademarks, copyrights, and patents. Furthermore, the process and costs incurred in pursuing and maintaining a patent are described. Finally, the faculty is encouraged to view their participation as guides to the team, thereby not appreciably involved in the generation of any IP value. If this were not so, then the university legal department would insist on retaining a percentage of the IP, severely constraining the sponsor, especially since few of the sponsored projects achieve any IP value. A side issue is that many sponsors will not provide necessary project technical details until all NDA and IP agreements have been signed. Ideally, project definition should be completed in the late Spring and legal issues such as NDA agreements formulated and signed during the summer before the semester starts. If not, this frequently restricts student access to necessary information until late in the first semester of the two-semester sequence.

A final legal issue that industrially sponsored projects can face occurs in industries supporting the defense sector. While confidential or secret work is rarely brought to the university, technologies utilized or applied can be covered under the ITAR [International Traffic of Arms Regulations] and DOC [Department of Commerce] restrictions. This limits access and disclosure to U.S. citizens or residents with Green Cards. In many cases, team member selection and faculty mentorship assignments have to consider their immigration or citizenship status.

Professionalism

A final issue to address in dealing with industrial sponsorship is to convince the sponsor that their investment of supporting funds and mentorship labor will be matched by student and faculty commitment to adequately work on their defined project. At times the scope of these projects is too aggressive for the students and project goals have to be redefined / renegotiated through discussions between the team, the sponsor and the faculty advisor. This however cannot occur in the last weeks of the academic year. Therefore, at UConn, we have made a commitment not to pass student teams that do not adequately complete their design project. Over the last three years, more than one quarter of the teams do not finish at end of academic year. Sometimes only a couple of weeks of dedicated work is necessary to complete the project, but frequently lack of student dedication throughout the year can extend the course completion date for several months. The above issue is treated at UConn as an informal contractual commitment between the team, the sponsor and the university. It requires the students to recognize that project timelines may force them to adjust their plans for intersession and spring breaks.

In order to foster a more professional relationship between the team and the sponsor, the teams meet regularly with the sponsor assigned mentor, goes onsite to present their design ideas, and have the sponsor designers perform a Critical Design Review [CDR].

Upon completion of the design project, the teams are encouraged after finals / graduation to make an onsite presentation describing the details and demonstrating their design. Correspondingly, the sponsors provide feedback on the design experience. We also encourage the sponsor to define what their technical and manpower capability requirements will be. In particular, one sponsor[6] circulates the traits listed in Table 2 as being typical, with "passion" as number one.

Table 2. Sponsor Identified Critical Skills for New Hires

Passion	Action [vs. Watching]
Optimism	Teamwork / Collaborator
Business View	Technical Competence
Historic perspective	Communication
Product knowledge	Action [vs. Watching]

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