

## **INSTITUTIONALIZING A SUCCESSFUL CAPSTONE PROGRAM – THE DEVIL’S IN THE DETAILS**

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### **Abstract**

The successful institutionalization of the capstone engineering design course in the Department of Industrial and Enterprise Systems Engineering (IESE) (formerly known as the Department of General Engineering) at the University of Illinois, Urbana-Champaign has been a process of analyzing all aspects of the program such that it can run efficiently and almost autonomously within the Department. This requires that all Department resources are used effectively and that the impact on other Department functions is minimal.

This capstone program has evolved over a forty year period into course which annually does forty or more industrially sponsored semester-projects, each of which has a three-student team and is advised by a faculty advisor. The course goal is to prepare students to work successfully in a commercial engineering environment. Projects are therefore scoped to be identical to those encountered by an entry level engineer in industry. Each project has a specific scope of work to be accomplished and a set of deliverables which include the problem solution, specific recommendations, and a supporting economic analysis, typically showing a two-year payback or better. The student teams make several trips to the industry sponsor, meet semiweekly with their faculty advisor, and maintain weekly communication with their sponsor contacts. Many presentations and reports are given throughout the semester, including the final presentation to the sponsors and the final report.

Because of the extensive nature of the program, involving all faculty, dozens of sponsoring companies, all senior undergraduates, several lab facilities, equipment purchases, travel, etc., the potential for chaos is great. Also, because projects vary widely from semester to semester with respect to equipment needs, software requirements, lab space, safety, intellectual property, etc., the management and operation of the program must be highly responsive to issues that arise. This responsiveness is based on (1) analysis and review of all known aspects of the course, (2) establishing procedures and policies for these areas, (3) effectively interfacing with company sponsors, faculty, other departments and university administration, and (4) a program administrator who can communicate externally with sponsoring companies, as well as internally with faculty, staff, students, and university administration.

Specific areas addressed are program marketing and solicitation of projects, self-funding of the program, creating a sustained marketing effort, scoping of reasonable projects, interfacing with industry sponsors, data management, program staffing requirements, working with faculty, establishing project standards, selection and management of equipment, labs and software, reasonable and effective prototyping procedures, safety guidelines, dealing with intellectual

property and non-disclosure issues, requirements for economic analysis, presentation standards, report formats and standards, managing sponsor expectations, meeting ABET requirements, and capstone program recognition.

All of the above items, when managed appropriately, serve to create an effective, self-funded, and highly accepted capstone program which is seen as a benefit to the engineering department and curriculum.

## **Introduction**

Before discussing details about a successful Capstone Engineering Project Program, it is important to understand the nature of the beast. The capstone course is a required course for all undergraduates, and typically involves more resources than any other activity in an engineering department. The program in the Department of Industrial and Enterprise Systems Engineering at the University of Illinois, Urbana-Champaign has about forty industrially sponsored projects each year. With all the students, faculty, staff, company sponsor personnel, student travel, purchasing, varied lab space requirements, equipment, project variety, etc., etc., the potential for chaos is enormous. For the program to be continually successful, it must be managed proactively with anticipation of issues that will arise. The program management must have an ISO-9000 “mindset” with habits of continuous improvement, preventive measures and corrective measures. This will increase the program’s signal-to-noise ratio and help keep quality high.

For many companies who deal with engineering departments with respect to research sponsorship, grants, etc., the capstone project may be their first introduction to the department. A positive experience here is vital for continued involvement. Unlike other courses taken by undergraduates, “failure is not an option” must be the attitude of all stakeholders involved with the project. Careful balance is needed to provide a challenging experience for the students - every time, and successful project results - every time. All this must be done within the resource capabilities of the engineering department and its other competing priorities. When this balance is achieved, all parties benefit from the program. For this balance to be achieved, the devil is truly in the details.

## **The IESE Department**

The Department of Industrial and Enterprise Systems Engineering was recently formed through the merger of the General Engineering (GE) Department with the Industrial Engineering (IE) group. The IESE Department continues to have curricula in Industrial Engineering and General Engineering.

The GE curriculum includes the typical engineering core courses similar to mechanical engineering in the first five semesters. The GE degree includes a “secondary field” of concentration which consists of four related courses in a specialized area, such as controls, robotics, manufacturing, bioengineering, engineering administration, etc. Various secondary fields make GE very interdisciplinary, permitting great breadth in capstone of projects.

The Industrial Engineering is typical of most IE programs throughout the nation. Special emphasis is placed on operations research. Due to significant overlap between IE and GE curricula, GE and IE students are intermingled in the various capstone project teams.

### **General Structure of the Capstone Course in IESE**

All projects in the program are sponsored by companies who have a financial interest in the success of the project. A fixed donation is required to cover the necessary costs of travel, equipment, prototyping, etc. All projects must contain an economic analysis to justify all recommendations resulting from the project, typically requiring a two-year payback.

Each company supplies two contacts for each project. The administrative contact typically initiates the project and handles all the necessary paperwork, but is at a management level which precludes weekly contact with the students. A technical contact is also designated, who has intimate technical knowledge of the project and can be available to the student on a weekly basis for phone calls and other needs as they arise.

Project teams consist of three senior undergraduate students from the GE/IE curricula with a faculty advisor dedicated to the project. Project duration is one semester or seventeen weeks. Students understand that all projects have been carefully scoped and evaluated to be doable and reasonable, and can be completed by semester's end. Students also understand that the project must be completed to a high quality standard and the problem must be solved for their grade to be assigned. On occasion, project teams have spent several weeks after graduation to complete their projects and receive their grades and degrees. Thus, students become very real stakeholders in project success.

The students and advisor are required to make an initial trip to the sponsoring company at the beginning of the semester to meet all involved personnel, tour the facility, understand the focus of the project and its economics. They must "follow the money" and understand the overall business process of the company. The initial trip involves photos, samples, drawings, information exchange, signing of nondisclosure and/or other required agreements. The students return to the company several times throughout the semester without the advisor for additional meetings, tests, presentations, etc.

Communication is essential and stressed. Students must interface effectively with several layers of management and many company areas, including design, manufacturing, accounting, IT, quality, etc. Professionalism in communication must be learned along with methods to overcome communication barriers. A weekly student team conference call with the company is a minimum requirement.

Each team must perform an initial analysis of the problem to determine status. The team must determine the proper metrics, apply them to the current state of the project/problem, and draw initial conclusions to give direction for the remainder of the project. Essentially, they determine what is good, what is bad, and then map their strategy. This also includes an initial economic analysis to determine the potential annual savings or profit potential, which is used to calculate the upper bound or maximum budget for all final recommendations, given a two year payback

requirement. The initial analysis lasts from four to six weeks and helps the students go through the learning curve for the project as they begin to know and work with company personnel.

The next step is solution development, during which the students do experiments, tests, designs, etc. Weeks six through twelve should see a dramatic ramp-up in team productivity and understanding. As analyses are completed, deliverables begin to take form. Software is designed and tested, prototypes are built (often using company tool room facilities), and solution alternatives are evaluated for final selection and development. Solutions, are then evaluated with exactly the same metrics that were used in the initial analysis to determine status. This will show the amount of expected improvement and allow for completion of the economic analysis.

The final weeks include many reviews by the company for compliance with the project scope and deliverables. Costs and benefits are estimated and economic analyses are completed, including a net cash flow diagram, calculation of payback period or simple cash recovery, net present value (NPV), and return on investment (ROI). A final reports and presentations are generated. All deliverables are sent to the company, including a CD of all student work product.

Thorough and continual communication with the company is vital to project success. There should be no surprises at the end of the project. If, at the end of the semester, the company contact says, "Gee, I wonder what the students will come with?" the project is a failure as far as project management and effective communications are concerned. The validity of the final solution and the economic analysis would be immediately suspect. The IESE program requires that the company endorses the final technical solution and economic analysis before the project is considered complete.

Several project management features are built into the program. Advisors are encouraged to meet twice weekly with their teams for at least the first eight weeks to manage the learning curve and direction of the project. Students attend weekly lectures by the Course Chairman (CC) in the how-to's of engineering projects, including communications, meetings, presentations, reports, and many common sense issues that arise, such as how to deal with a client as a consultant. The CC meets with each group individually to discuss initial analyses, direction and strategy. Each team must rewrite its problem statement, scope and deliverables at the end of week five and get written approval from the company. This promotes communication and prevents scope creep. Every three weeks, the company must fax a one-page, project feedback form to the CC for evaluate project status and progress from the company's point of view. This allows adjustments to be made as necessary in the team-company interactions.

Four team presentations are given during the semester at weeks five, ten, eleven, and seventeen. The first is given to groups of students and faculty to evaluate the team's project understanding and direction. The second should demonstrate a potential project solution with preliminary economics. At this point, presentation feedback is candid and demanding. The third is given at the company facility before their management and any other personnel who have any connection to the project and its outcome. This third presentation is a tremendous experience for the students and a great help for project progress. All ambiguities should be eliminated, and the final five weeks of the project should be clear. The final presentation is given during final exam week and is attended by all sponsoring companies.

Four reports are required, including a “pre-report”, a midterm, a draft of the final report at week thirteen and a final report at the last day of classes. The pre-report at the fifth week, includes intro, problem statement, and team objectives, but no analysis. All later reports are to be as complete as project progress allows.

Students earn five semester credits. A grade for two credits is assigned by the advisor for each team member’s effort. Another shared grade of three credits for the project itself is assigned by a committee of two other faculty members.

### **Program Management Philosophy**

The management of the program must be very responsive to many needs of many parties, who often have different priorities. Capstone management must be proactive to anticipate and prevent problems as well as quick to resolve issues. The program must also be designed to minimize necessary faculty involvement without compromising quality. Administrative issues with students, purchasing, reimbursement, travel, hotels, equipment checkout, use of labs, use of campus and third party resources, report formats, course requirements, economic analysis requirements, etc., must all be communicated to the students through the CC and capstone staff. This will unburden the faculty and allow them to concentrate solely on the technical portions of the projects and project management.

The IESE program incorporates a handbook which covers all features of a generic capstone project from start to finish. This is no-nonsense information which is a complete, readable, and written with the student in mind. This is a working document which is continually edited as needs change. The full-time, three-member capstone staff, including the CC, a Program Administrative Assistant, and a Secretary, are always available to answer students’ questions and meet their needs without involving the research faculty. The bottom line: This is new territory for most students and they must have lots of guidance to be successful.

The capstone staff and CC must have extensive experience and have developed a corresponding degree of autonomy to resolve issues immediately with minimal involvement by other department administration. The philosophy is “solutions should be many and problems should be few.” If the capstone program repeatedly brings problems to the department administration for them to solve, the program itself will eventually be seen as the problem.

Over time the program should become self-funding and be able to bring in excess funding for the overall health of the program and for potential other uses in the department. This is achievable by keeping project quality high, maintaining company relationships, and incorporating checks and balances into the program. The program will become a long-term asset to the department and a source for expanded corporate involvement.

### **Project Marketing**

“Get out there.” This is the secret to marketing success. In addition to the obvious mailing lists, letters, phone calls, etc., the most effective method is personal contact with the company client.

This allows relationships and confidence to be built quickly, along with commitment to program participation.

The IESE program hosts a number of conferences in centralized industry/business locations to which company decision makers are invited through mass mailings from pre-qualified lists. About 1-3% attendance is typical. The presentations are brief, to the point, and discuss the project program and how the projects are managed with a strong hand. Decision makers want to see strong management and a high probability of success. Brief project examples are also given demonstrating several project types, technologies, and solutions. Keep in mind that they want to see results. The solutions should be seen as valid, reasonable, doable, and profitable.

Initial contacts are made at the conference, to be followed up by phone calls to discuss project ideas with the company contact. The CC writes all project documentation and sends to the contact for review. This makes the exchange fast and easy for the company. Typically few if any edits are required and the documentation is complete.

The next step is a trip to the company site by the CC to meet company personnel, see all aspects of the project, tour the facility, take photos for the initial presentation of the projects to the students, and review of the company sponsor handbook, which describes the company's participation and gives guidelines for project success. This trip is vital to cement the relationship with several company personnel, and to make sure the project is reasonable and doable by undergraduates. Scope can be managed or adjusted to ensure success.

The travel commitment is substantial for the forty IESE projects per semester. Typically, two to four companies can be visited in a day. Maps, directions, GPS, are critical for keeping schedules with many busy company clients. The IESE CC traveled a total of 7342 miles for the twenty seven projects for the spring 2007 semester. Typically, forty to fifty manufacturing plants are visited annually.

## **Scoping Projects**

Determining a proper project scope is one of the most important tasks for project and program success. Because students typically have little real-world experience, highly focused and well defined projects are desirable. Care is taken to make sure the learning curve is not too long for the length of the semester. Students must be able to get their arms around the project in time to be productive and find the solution. There is a tradeoff between intensive and extensive projects. Intensive projects are highly focused and typically have large research content, whereas extensive projects may involve so much information that the students become overwhelmed and have trouble focusing on a solution direction. Project scopes can be altered to provide a "win" for all parties concerned. Companies would rather have a smaller success than a bigger failure.

To scope the projects the CC has familiarity with the undergraduate curriculum, the faculty strengths and preferences, and a broad range of technologies. It is also necessary to be familiar with the reasonable deliverables that bring a project to completion from the company's standpoint. Some projects may include prototypes, software development, or other deliverables which must be completed in addition to the report. Logistics must be considered for fabrication,

testing, machine shop resources, interfacing with company IT systems, etc. Any project feature which depends on a third party for project progress or completion poses a risk to the project and must be managed properly beginning with the scope.

## **Working with Students**

Working with students successfully is a matter of getting their attention, changing their learning paradigm, and giving lots of direction and support as they work their way through their projects. First lectures are designed to impress upon the students the course requirements, the enormity of the task in front of them, the helps they will be given along the way, and the pitfalls that most will fall into, mostly from their own bad habits. The students' initial learning paradigm is "lecture-textbook-homework-exam" – meaning that they don't have to know much of anything until the day of the exam. This paradigm is useless in the real world, where project success is determined by steady learning, asking questions, meetings, research, doing today's work today, and being responsible and accountable to the team. To help change their paradigm, short video interviews are shown of students who have just completed their projects and are giving advice to the upcoming class. This gives credibility to the notion of front-loading the project with as much work as possible.

Initial advisor meetings and CC meetings are designed to load the students with tasks to help them go through their learning curves as quickly as possible so they can take positive actions as soon as possible. This is extremely important. Many students have become so conditioned to studying for quizzes and for exams that it becomes difficult to focus on longer term goals. It is only after going through the initial learning curve that the students feel comfortable with their projects and confident about their success. Then, their project work becomes satisfying.

Emphasis is placed on the transition from being an engineering "student" to becoming functioning engineer. All students are expected to sign a non-disclosure statement prepared by the company to be executed at the first company visit. This is described as a "right of passage" for any engineer working in a commercial environment. Students are urged to change cell phone voicemail prompts to be professional in nature. Methods of dealing with vendors and getting proposals and quotes are discussed. Professional presentation methods are taught so the student can be compelling and convince the listeners to take action. The overall goal is for the students to be matured and changed by the project experience.

## **IT Support**

Capstone project activity data management requirements are significant and must be handled properly. The IESE program uses an MS Access database which manages information for all students, faculty, companies, mailing lists, grading, maps, equipment management, project data, accounting, billing, conference coordination, name tags, etc. The database was custom designed for the specific business processes of the activity and is modified as the need arises.

Computer lab software needs are extensive. Software is kept on each machine for CAD, FEA, CFD, statistical analysis, flow charting, and other general purpose applications. Specialized

software is purchased on an “as-needed” basis. IT support is very flexible and highly responsive to project needs.

### **Lab Facilities and Equipment**

Lab facilities consist of a thirty computer workstations, an equipment storage area, rapid prototyping machines, and a “dirty” lab area for miscellaneous experiments, mechanical analysis and disassembly. IESE department lab facilities are designed to be generic but flexible to meet varying project needs. Relationships are made with other departments for use of specialized facilities.

Equipment for the course is intended to have broad application for many projects. This includes tool kits, oscilloscopes, data acquisition systems, scales, calipers, etc., along with many software packages and reference books. Specialized equipment is purchased as needed. Non-consumable purchased equipment is inventoried for use in later projects.

### **Proprietary Information and Intellectual Property**

The IESE capstone program treats all reports and other company information as proprietary and does not allow publishing of any project information without written permission from the company. This policy is necessary for continued work in the commercial engineering environment. Non-disclosure agreements for faculty and students are typical and handled by the companies for their specific needs.

A special arrangement for intellectual property has been developed to allow the company participants to own any resulting IP without University involvement. This is necessary for the promotion of product development projects which may develop IP. The companies prepare their IP agreements with the students, to be executed at project start.

### **Safety and Liability**

Safety is a continual concern both on and off campus. Companies must understand their liability, and are therefore sent certificates of insurance showing student coverage for all capstone project work. Students are given safety lectures, applicable equipment and instructions. This is an area of constant review. The CC and program staff must demonstrate due diligence in the safety area. This has resulted in no injuries in the forty year program history.

### **Program Recognition**

Program recognition helps tremendously with program acceptance and institutionalization. Many national engineering project competitions exist which can be entered. Some competitions are project specific and involve the same scope of work for all participants, with a monetary prize for the winner. Other competitions, such as the James F. Lincoln Arc Welding Foundation Engineering Student Design Competition, Division IV, provide a level playing field for all engineering disciplines. The IESE program has been recognized many times in this competition over the past several years.

## **The Devil's in the Details**

Long term success in the capstone program is a matter of understanding, managing, and controlling numerous details. In many cases, “control” is an illusion – it amounts merely to closely managed chaos. *Without* proactive management, chaos can easily become overwhelming. *With* proactive management, success is achievable.