Designing and Teaching a Successful Industry Based Capstone Design Course

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I. Introduction

The challenge for manufacturing companies is to design and manufacture high quality products, on time and at minimum cost. As a consequence, the need for well-rounded engineering graduates who can contribute directly to the growth and profitability objectives of the company is critical. Thus, the required core competencies extend beyond technical ability to include: effective communication skills, planning and prioritization, time management, working in teams, and knowledge of the financial aspects of the business [Helms, 1995]. Unfortunately, these competencies are among those identified as key weaknesses of the engineering graduate. Hood, Sorensen and Magleby [Hood,1993] list the weaknesses identified by industry to include: 1)weak communication skills, 2) poor perception of the overall project engineering process, 3) little skill or experience working in teams, 4) a narrow view of engineering and related disciplines, 5) no understanding of manufacturing processes, and 6) a lack of appreciation for considering alternatives. At a recent "Voice of Industry" workshop sponsored by the Penn State University, for the National Coalition for Manufacturing Leadership, the consensus opinion of the industry participants seconded that two of the major skills in which engineering graduates were weak are interpersonal and communication [NCML,1996]

Consequently, the Penn State Industrial and Manufacturing Engineering (I & ME) department has designed a Capstone course to address these weakness. The Capstone course began in the Spring of 1994 as a joint effort between Industrial and Aerospace Engineering to design and manufacture a full size sail plane. By the fall of 1995 the course had expanded to 10 projects; all of which were inter-disciplinary. Examples of projects include: design and fabrication of semi-automated terminal insertion apparatus for a Gigafilter production line; design and development of a computer network system to link PC's together; and determination of methods to improve the productivity of steer loader production lines. Teams are typically comprised of two to four students. The course is offered in one semester for 3 credit hours. Grading is based on team accomplishment, peer performance evaluations, written reports (proposal, progress, and final reports), and industry sponsor evaluation of team performance.

This paper describes the necessary components in the design and management of this successful capstone course. Attention will be given to the approach to teaching the course, as well as how the course is conducted. Of specific interest are the roles of the instructor, student, and industry sponsor in the learning process. Finally, the impact of the course on the student, the sponsor, and the department are discussed.

II. Approach

The approach to the I & ME capstone industrial project design course is to construct learning objectives which address the aforementioned weaknesses of the student by immersing the student in real life professional problem solving experiences. These learning objectives include: effective application of problem solving techniques, understanding the financial impact of problem resolution, effective communications, the ability to work in teams, understanding of the relatedness of multiple engineering disciplines, knowledge of manufacturing processes, and an appreciation of alternative solutions. A multi-tiered instructional approach is used which includes a series of lectures, panel discussions with manufacturing consultants, meetings with industry sponsors, report writing, class and industrial presentations, and invited speakers.

The student's real life professional problem solving experience is accomplished primarily by the instructor guiding and coaching the student rather than directing them in solving the problem. Exposure to the uncertainties and the dynamics of every day business such as: changes in problem parameters, insufficient data, lack of clarity about the customer or sponsor's needs, misunderstanding regarding the identity of the real customer (or customers), impromptu presentations, meeting deadlines, discovering corrupted data, understanding/working within the corporate culture and the politics are important aspects of problem solving. All of these variables must be managed in order to produce deliverables. Typically the courses that students will have taken by their senior year have no such uncertainties. In most cases the input parameters are available and the problem is well defined. Thus students are essentially taught to skip critical steps in the problem solving process and asked to start with the analysis. However, these steps can be the most challenging part of problem solving; usually taking a considerable amount of time (threatening deadlines); and requiring ingenuity, team work and patience. Students who have grappled with such real life problems prior to graduation (usually through internships and co-op experiences) are preferentially sought by industry because they can perform in a professional capacity more quickly and with less training than their peers.

To facilitate this learning process the following guidelines were employed as goals by the various entities involved:

College

1) Develop strong partnerships/commitments among the faculty and the administrative staff in the participating departments (e.g. Mechanical, Aerospace and Industrial Engineering
2) Promote interdisciplinary projects to prospective students throughout the college.
3) Provide equivalent credit for the capstone design course for all students regardless of department.

Industry Sponsors

1) Provide time and other resources as necessary to assist the student.
2) Engage early in the project to ensure that the problem is well defined.
3) Select projects that require an interdisciplinary effort and can be solved within the semester time period.

Instructors

1) Select sponors that that are committed to enhancing engineering education.
2) Monitor the relationship with industry sponsor to ensure that expectations are being managed.
3) Maintain the role of a coach and consultant to the student; rather than supervisor or problem solver.
4) Monitor team progress by establishing regular meetings

Students

1) Take full responsibility (ownership) early in the project.

III. Course Conduct

By the end of the semester the student solves a problem identified by an industrial sponsor and produces one or more of the following tangible deliverables: recommendations, models, designs, hardware, and/or software.

The course conduct described herein is really a procedure for addressing the problem. In figure 1 the conduct is described in procedural steps. The procedure begins with the solicitation and selection of industry projects. Months prior to the start of the course instructors from participating engineering departments solicit interest from local industries via meetings and written correspondence. Instructors then compile a comprehensive listing of projects. At the first class meeting of the semester students are made aware of the projects. Each sponsor has prepared a one-page description of the problem that they have identified and copies of this page are distributed to the class. At the close of the first scheduled class, students are encouraged to pursue information about the available industrial projects through talking to faculty, teaching assistants, and the industrial sponsors' liaison engineer.

The second scheduled class meeting is for the students to ask questions about the course conduct, project conduct, specific industrial project problems, and any other matters relevant to the course. Instructors and many of the sponsors' liaison engineers are present to answer questions at this session. At the end of the day of the second class meeting, the individual students are required to submit their prioritized choice of the three projects to which they wish to be assigned. Also, they must submit a half page description of their qualifications and a justification for being awarded their first choice. In addition, they must submit a weekly schedule for the semester, because one criteria for team composition is that all members must have the same one-half day free each week so that they can visit the sponsor's facility as a team.

Prior to the third class meeting, instructors meet to select projects (based on the level of interest) and assign teams to specific industrial projects. Faculty members then decide who will advise the various teams. In the third scheduled class meeting, the students are organized into these teams. During this meeting, the teams conduct their initial meeting and begin developing plans to learn more about their assigned project and sponsor, and to arrange a visit to the sponsor. They are reminded that a proposal describing their investigative approach in due in two weeks.

For the next two weeks, the students schedule meetings with the instructors (professor and teaching assistants) and the sponsor's liaison engineer as needed. There is at least one scheduled, one-hour, meeting with an instructor during this period. Also, during the class meetings, tutorials and lectures are conducted regarding teamwork, project management, effective presentations, time management, cost/benefit analysis**,** writing company memos, and dealing with difficult interpersonal situations. Further, the students are made aware of facilities and administrative support that are at their disposal to conduct their projects. These include shop facilities, computer laboratories and software, and project administrators. In the seventh class meeting, the students must submit a written copy of their project proposal and present their proposal in the form of a talk to the class. Following this session, they are required to make a presentation to the industrial sponsor's management at the sponsor's site. A copy of their proposal is also presented to the sponsor.

For the next three weeks, the students conduct their team project investigation interfacing mainly with the industrial sponsor's liaison engineer and visiting the industrial plant site. Meetings with the instructors are scheduled at least every two weeks and the team is coached and advised, particularly with regard to problems that have impeded its progress. Also, every two weeks the team meets with a panel consisting of faculty, industrial visitors, and graduate students. During this panel meeting, the team is interrogated regarding their decisions and investigative approach.

In the fifteenth scheduled class meeting, the teams are required to submit a written progress report and present this report orally to the class. Following this, the written and oral report is presented to the sponsor. The next four weeks are conducted much the same as the previous three weeks with meetings, sponsor visits, and panel sessions.

The teams written final report is due the first scheduled meeting session of the last week of classes. Following this, during the last week of classes and final examination week, the teams orally present their final reports to the class, and to the sponsors at their industrial facility.

IV. Conclusions

Thus far, the project results have met or exceeded the expectations of the industrial sponsors, students, and faculty. The process by which these deliverables are produced (See figure 1) provide direct and indirect benefits for all concerned. For the industry sponsor, a key benefit is that the deliverable is most often put to use. This may mean taking action by implementing the proposed solution, avoiding costly alternatives previously considered, using new suppliers identified by the project team, or even the re-organization of groups within the company to address needs previously ignored or misunderstood.

Additionally, company sponsors have started to use the experience as an effective recruiting tool. Many of our graduates have been offered positions with the companies with whom they worked due to their recognizing the skills of a particular student. In most cases sponsors are eager to repeat the experience and some have continued their partnership for years. Indirectly, a company also gains benefits from their participation in enhancing the quality of the graduating engineer.

Although the deliverable is important for the student, the experiences gained from the process is of primary importance. Specifically, the students experienced:

- the difficulty associated with defining problems;
- the determination of cause and effect relationships,
- the management of impediments in obtaining information and approval,
- the presentation of their ideas to high-level managers and their peers,
- the conversion of the project worth to financial terms,
- the importance of written and oral communication skills from the sponsor's perspective,
- the coordination of efforts between a number of groups who may/may not work well together,
- the politics of the company and how it impacts work,
- the meeting of aggressive deadlines, and finally
- the delivery of a quality solution in spite of "real life" difficulties.

These experiences are invaluable in developing the students' ability to deploy their basic engineering skills to the professional work place. The experience builds confidence, provides an awareness, helps with the transition from theory to application in a relatively risk free environment and untimely shortens their adaptation to the job.

For the faculty and the department the benefits include a closer relationship with industry which often provides more opportunities for research sponsorship as well as more relevance and credibility of the academic program in the eyes of the industrial customers.

These successful outcome of the projects is the result of: establishing a strong interdisciplinary effort at the department faculty level; managing the expectation of the sponsor by providing continuous feedback; defining the roles of the instructor and student clearly; coaching and not instructing and finally accepting a certain level of uncertainty in the process.

References

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Hood, R.H., Sorensen, C.D., and Magleby, S.P., Designing a Senior Capstone Course to Satisfy Industrial Customers, *Journal of Engineering Education*, April,1993

NCML Voice of Industry work shop at the Penn State University, April 24, 1996, on of four such workshops organized by the National Coalition for Manufacturing Leadership.

Biographical Information

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Velma J. Deleveaux received a Ph.D. in Industrial Engineering from Pennsylvania State University in May, 1997; a B.S. in Industrial and Systems Engineering from Georgia Institute of Technology in 1983 and an M.S. in Engineering Science from Harvard University in 1989. She has worked for 9 years in manufacturing for Digital Equipment Corporation in the areas of applied statistics, operations research, and continuous quality improvement. Her current research interests include applied statistics and analytical models to justify investment in quality improvement.

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C.O. Ruud is a Professor in the Department of Industrial and Manufacturing Engineering at the Pennsylvania State University. He received a B.S. in Metallurgy from Washington State University in 1957, an MS. In Material Science from San Jose State University in 1967 and a Ph.D. in Metallurgy at University of Denver in 1970. His current teaching and research interests are in the area of manufacturing processing of materials and interdisciplinary education.

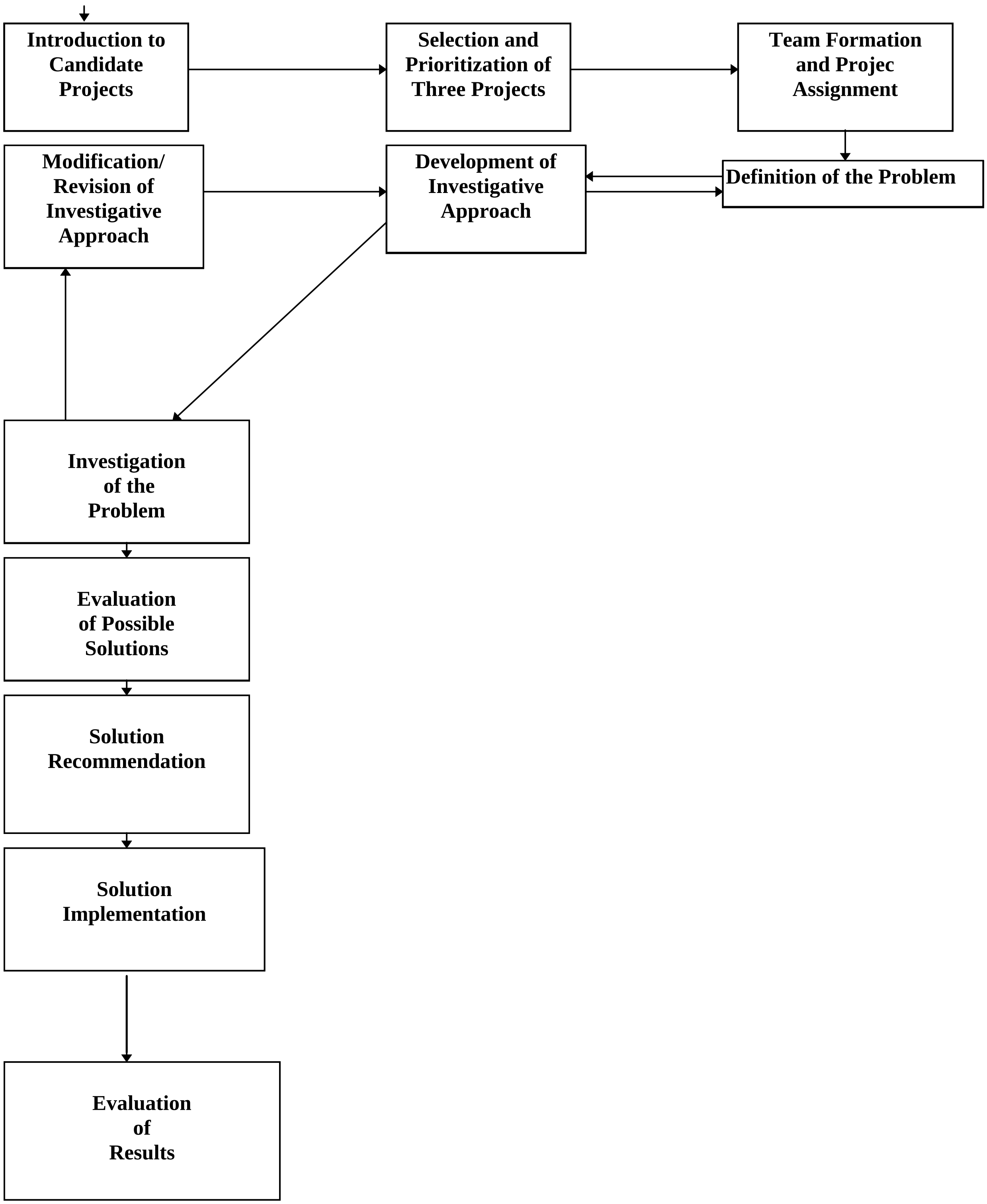

Figure 1. Process Diagram for Industrial Engineering Capstone Design Project Course