RECONCILING WELL-DEFINED CAPSTONE OBJECTIVES AND CRITERIA WITH REQUIREMENTS FOR INDUSTY INVOLVEMENT

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Abstract

Mechanical engineering capstone design students benefit from interaction with practicing engineers. This is widely recognized, and many programs require students to work on projects that originate with local industry. This approach has the appeal of "real-world" engineering, and the benefit of external project evaluation. However, it can be difficult to reconcile industry-sponsored projects with established capstone criteria regarding scope, objectives, and required elements. Such projects may be too large or too small, and they may encompass only a few aspects of mechanical engineering design. At its worst, different objectives on the part of faculty and industry representatives lead to confusion, resentment, and frustration for students.

Grove City College has developed a rigorous set of capstone requirements, including objectives, scope, topical elements, and evaluation criteria. Industry sponsored projects are occasionally done, but they are not actively solicited. However, involvement of practicing engineers from local industries is not only encouraged, but required. Student design teams, with the help of faculty advisors, identify people in local industries with skills beneficial to their particular project. These people are invited to help by 1) answering questions and offering advice to the student team, 2) participating in design reviews, and 3) evaluating student presentations. Many practicing engineers very generously donate their time towards helping the students. The result is an invaluable experience for most capstone students. This paper describes the Mechanical Engineering Capstone Design program at Grove City College, and how the program is enhanced by industry involvement.

Introduction

Capstone design programs are the culmination of an engineering student's undergraduate career. They draw on all previous course work in engineering science and design, as well as senior-level design topics. Providing a mechanism for students to interact with practicing engineers in industry is a proven way to enhance the learning experience for students. Likewise, learning is enhanced when program goals and requirements are clearly defined and supported by appropriate instruction. Capstone design programs are particularly effective when they are 1) comprehensive in scope; 2) contain well-defined goals and standards; and 3) include participation of technical professionals from industry. These three elements can be incorporated fairly easily when only faculty approve projects and evaluate all project outcomes. However, if these tasks are shared or delegated to industry representatives, conflicts may arise and the learning potential can be compromised. This in no way implies that industry representatives should not provide students with help and advice. It means that faculty – who are most familiar with program goals, requirements, and standards of learning – should be responsible for determining if student outcomes meet evaluation criteria. This prevents confusion on the part of the students in those cases where disagreement arises. It also clarifies the role of all participants -- students, faculty, and industry representatives.

The mechanical engineering department at Grove City College has developed a rigorous set of capstone requirements, including objectives, scope, topical elements, and evaluation criteria. Student teams are required to obtain input from representatives of local industries in the form of industrial advisors and design reviews. However, it is clear to students and industry representatives that project control and evaluation of outcomes are the responsibilities of faculty. Projects are selected by students, either from a list of options provided by faculty or from their own ideas. Industry-sponsored projects are not solicited, but are occasionally offered as suggestions. All projects must meet rigorous and explicit requirements in order to be approved by capstone faculty.

This model has proved very successful for Grove City College. Student success rates and student enthusiasm for the capstone design program are very high. The capstone program is enhanced by industry involvement, but students are not confused as to who is ultimately responsible for evaluating project outcomes.

GCC Capstone requirements

The Capstone Design Program at Grove City College's Department of Mechanical Engineering is aptly named, for it is comprehensive in both breadth and depth. Spanning the entire senior year with contributions from eight different courses, it draws on virtually all previous coursework. (The eight courses include a core design course in both fall and spring semesters; a lab course each semester, and other required or elective senior courses that include assignments related to the student's capstone project. An example of the latter is an elective finite elements course in which students must complete analyses of components in their capstone project.) Comprehensive standards for the capstone program are defined in the Capstone Design Handbook, which is provided to students and faculty. The standards include program goals, scope, assignments, evaluation criteria and completion standards. Student teams of six to eight students are permitted to select their own product realization projects, subject to specific guidelines and faculty approval. Input from industry is required (as described later in this paper) but industry-sponsored projects are not solicited. Project control remains in the hands of faculty.

Goals: The goals of the capstone design program are to:

- Teach students the principles and practice of mechanical engineering design within the context of a product realization process.
- Teach students to work together as members of a multi-functional design team.
- Develop students' problem-solving and critical thinking skills while fostering positive problem-solving attitudes.

Project Scope: All capstone projects must involve the design of a product that is to be produced in moderate to large quantities (no special-purpose designs.) The following elements must be included:

- Product Design Specification (PDS) developed in conjunction with real or surrogate customers and marketing departments
- A technical design solution that meets the PDS
- Complete virtual modeling of entire design
- Design verification -- with performance predictions -- using analyses and simulations
- Physical prototyping, testing and comparison with predicted performance
- An economic analysis to demonstrate financial feasibility
- Comprehensive manufacturing, tooling, and production plans

Additional requirements include economic and social impact statements, the inclusion of both mechanical and thermal/fluid elements, and development of a corporate identity which provides a framework for economic decisions. On occasion, industry-sponsored projects are undertaken, but they are scrutinized carefully to ensure that students can meet all scope requirements.

Student Evaluation: Capstone assignments are included in the Capstone Design Handbook. Assignments are selected to ensure that all required elements are completed in a timely manner. Evaluation criteria are included for all assignments. Completion standards are included for all applicable assignments. Depending on the nature of the assignment, credit is given to the entire team or the individual student responsible for the relevant area, and in some cases both individual and group credit is given. Assignments are coordinated between courses. For example, students taking Engineering Economy (spring semester) must submit a full economic feasibility study of their capstone project – one of the capstone requirements. Likewise, Finite Elements students must complete analyses of their capstone design special-purpose parts.

Each team is provided with a project web site on which most project documentation is submitted. The web site is considered a cumulative effort to document the entire project. In addition, CAD models for the entire design (including tooling models) must be submitted at the end of the year. Fully detailed drawings of each special-purpose component are also required.

Advantages: A structured, comprehensive design program enhances the learning experience for design students. A broad scope ensures that students are exposed to a wide range of problems and design tasks, fostering competence and confidence. Well-defined standards ensure students know what is expected of them, and help them accomplish project goals. Student enthusiasm is typically high.

Involvement of industry in capstone design programs

Capstone design students benefit in many ways from interaction with practicing engineers from industry. These benefits are well established, and have been discussed by numerous authors (Gibson and Brackin[1] for example.) However, most of the literature emphasizes projects provided by local industry. Several schools have well-established capstone design programs that use industry projects exclusively (Thigpen and Glakpe[2]; Ruud and Deleveax[3]; Bergman[4].) Others have expressed concerns about industry-sponsored projects, while looking for ways to increase industry involvement in their programs (Heitman and Manseur[5].) Typically, reservations are related to questions regarding a company's support for the project or the difference in priorities between the school and the company. An alternative solution, which has received very little treatment in the literature, is to explicitly require industrial input for student projects, without requiring projects to originate in industry.

Benefits and advantages of industrial involvement with capstone projects include:

Technical Expertise: Engineers working in industry typically have a great deal of technical expertise with the products and/or processes of their company. This expertise complements and augments that of faculty. For example, a faculty advisor in the area of manufacturing will rarely have in-depth practical expertise with all potential processes that students may specify. An engineer in industry working with a particular process on a daily basis can often provide a level of technical expertise that can not be found on campus. This is particularly true for the smaller schools.

Technical Experience: Engineers and technical professionals working in industry gain a wealth of practical design experience. This experience encompasses much more than the strictly technical aspects of design. As a result, they are often able to help students gain an understanding of design priorities and an appreciation of design methods, economics and other non-technical issues. This complements and reinforces what students learn in design classes. Some specific advantages include:

- **Design Priorities:** Students in capstone courses are required to both learn and apply a variety of design tools and methods. Faculty are tasked with providing a "general-purpose toolbox" applicable to a variety of industries and products. Students often mis-apply the tools, or mis-interpret the results. Engineers in industry are generally very quick to point out the problems that are most important for a given project and the best tools for tackling them.

- **Relevance of Design Topics:** Students benefit from seeing how the methods they study in design classes are used in "the real world." Some design topics are seen as irrelevant by students until they realize that these methods are routinely used in industry.

- **Importance of Economic Analysis**: The importance and relevance of engineering economic analyses is almost always emphasized when students discuss their projects with practicing engineers. Without this interaction, students sometimes consider economics to be irrelevant to design – a subject for business students.

- **Importance of Non-Technical Issues:** Frequently the success or failure of a new product or design is due to non-technical issues. Engineering students often underestimate the importance of marketability, legal issues, codes and standards, product safety, environmental issues, etc. These are frequently emphasized by practicing engineers.

Industry-sponsored capstone projects

Many schools use projects that are provided by industry as a means of incorporating industrial participation in their capstone design programs. These projects can offer all of the benefits described above, as well as the excitement of working on a "real-world" project. However, there are also several disadvantages and special challenges associated with industry-sponsored projects. These include:

Limited scope of projects: The greater the intended scope of a required design project, the more difficult it becomes to identify a suitable need in industry. Any design experience deserving the name Capstone is necessarily comprehensive in scope. For example, Capstone students at Grove City College must design a product from conception through detailed design, including tooling design and production planning. Marketability assessment, tooling design, plant layout, environmental concerns, and economic performance predictions are among the required elements. It is much more difficult for partners in industry to provide problems that meet these extensive scope requirements while still providing a tractable design task. Perhaps the best place for industry-sponsored projects is not in Capstone courses, but in smaller design projects associated with other, non-capstone courses.

Potential conflict of goals or expectations: Inevitably, the goals and expectations of a faculty member differ from those of the industrial sponsor. This problem can be minimized if faculty make a concerted effort to communicate project requirements and expectations to both students and industry representatives, but the potential for conflict can not be eliminated. The problem is exacerbated when an industrial contact is transferred during a project. Companies occasionally terminate support for a project. The worst case scenario is that in which the industry representative has dramatically different expectations from the faculty for project deliverables. This leads to confusion and frustration for the students.

Faculty preparation time: Solicitation and selection of appropriate projects requires faculty to invest substantial time over and above that required to advise the technical development of a project. Gibson and Brackin, of Rose-Hulman Institute of Technology, estimate that for a one-semester course in which the industry-sponsored design project counts 50% of the grade, faculty must spend 115 to 200 hours on project selection before the semester begins (Gibson and Brackin[1].) Considering advising a design project is a time-intensive task, this extra workload may be considered excessive.

In addition to these concerns, there is the increased pressure for students to perform well. This can be both and advantage and a disadvantage. Additional pressure can motivate students to perform their best. It can also lead to increased frustration and embarrassment when the project does not work as well as it should.

Reconciling industry involvement with capstone requirements

The Mechanical engineering department at Grove City College not only expects, but requires industrial participation in senior capstone design projects. Industrial sponsored projects are not solicited for capstone courses, and only occasionally implemented. (Although in non-capstone design courses with much smaller project scope, industry-sponsored projects are frequently used successfully.) Every capstone project nonetheless receives significant input from industrial representatives in the form of industrial advisors, design reviews, and project evaluations. Vendors willing to cooperate with students are also solicited. Specifically, these policies are implemented as follows:

Industry Advisors: Whenever possible and appropriate, student design teams are provided with contacts in industry with expertise in areas related to the project. Students then contact these advisors for help in specific areas. For example, a student team that is designing several injection-molded parts may be provided with an engineer in a company that produces similar parts. Students may telephone, email, or visit the representative with questions. This is an excellent way take advantage of professional expertise.

Industry advisors should be recruited by faculty. The Grove City College faculty has found that many engineers in industry are more than happy to help, subject to their work schedules. Establishing these ties is crucial to a successful program. Sources of new contacts include alumni and local chapters of engineering societies such as ASME, SME, NSPE, SAE, etc. In all cases, the faculty advisor should clearly convey to students the importance of honoring the industry advisor’s time constraints. An excellent contact can be lost if students are not respectful of his or her time.

Design reviews: Each capstone design team is required to conduct at least one design review with engineers and other technical personnel from local industries. The objectives of the design review are to 1) identify deficiencies or problem areas in the students’ design, and 2) improve the design. Students begin the review with a presentation of their project. An open discussion follows in which the reviewers (and students) ask questions, evaluate the proposed design, and offer suggestions for improvement. Technical drawings, virtual or physical models, and other data is provided to assist the reviewers. Invariably, design reviews are valuable experiences for the students.

Faculty advisors assist students with locating appropriate professionals and scheduling the design review. Generally, the review includes three to five professionals with expertise related to the project. It may be conducted either on or off campus to best accommodate the schedules and needs of the reviewers

Successful implementation of design reviews requires the following:

- Establishing and maintaining a pool of technical professionals in industry that are willing to provide their time to help a student design team. Often, industrial advisors are also willing to participate in design reviews. Additional reviewers can be recruited using similar strategies.

- Assisting the students to prepare for the design review. The quality of the design review is dependent on how well the students communicate their design objectives and solutions. Student teams should be coached in preparing a professional design presentation and how to conduct the design review. In general, faculty members participate in the design reviews, but let the student team leader conduct the review.

- Conducting a post-review critique. The value of a design review is greatly enhanced when faculty conducts a critique one to two days afterward. Students should have a chance to think about reviewers comments for a day or two prior to the critique. The critique helps students to interpret comments of the reviewers and focus on the top priorities. Generally, design reviews result in copious amounts of information, not all of which is equally important, and which may be contradictory. Students often need help prioritizing the data and developing plans of action.

Project Evaluation: At the end of the year, students are required to make a final presentation of their design project to faculty, college administrators, underclassmen, and parents. These presentations are evaluated by representatives from local industries. Frequently people other than industry advisors are used, although there is some overlap. Although the project is essentially completed by this time, the comments of evaluators are still very helpful to the students.

Vendor Participation: Grove City College actively searches for vendors that are willing to provide additional assistance to students. Frequently this takes the form of reviewing designs for parts and making recommendations regarding part design or tooling design. For example, a local foundry is very willing to review students' designs for sand-cast parts prior to providing a quote. In addition to providing technical recommendations regarding castability, potential hot spots and other problems areas, cores, etc., they give students a tour of the foundry and help to familiarize them with the casting process. This has tremendous value to the students.

Grove City College has found that these methods are very effective for incorporating industry representation on capstone design projects. The broad scope rigorous content requirements of the capstone program make industry-sponsored projects challenging – both for the faculty selecting projects and for the students completing them. (The most successful industry-sponsored projects have been those in which students and faculty were given the greatest control over project definition and evaluation criteria.) In general, students receive excellent support from industry advisors and design reviews. These augment faculty expertise and offer students a flavor of "real-world" engineering.

Assessment: The current philosophy regarding industry participation in capstone projects has evolved over several years. Many elements, including design reviews and vendor participation, have been used on an ad-hoc basis with some design teams for several years. No formal assessment existed in these early years, but two criteria attested their value. First, student response was very positive, almost without exception. Second, faculty observed positive reinforcement of the topics covered in the curriculum. An early attempt to assess design reviews by tracking the number of resulting design changes proved ineffective, and was subsequently abandoned.

All elements described in this paper are now formal components of the Grove City College capstone design program. In the 2001/2002 academic year, formal assessment is limited to student questionnaires. However, assessment of industry-involvement programs is currently being reviewed in the hopes of identifying better metrics. Evaluating the technical content of student/industry interaction is one aim. Assessing the contribution of student/industry interaction with respect to Grove City College Mechanical Engineering program goals is a second. The new assessment tools will be implemented in the 2002/2003 academic year.

Conclusion

Capstone students benefit from a comprehensive, structured design experience that does not rely on industry-sponsored projects. The manifold benefits of industrial participation are obtained by 1) providing industrial advisors; 2) requiring students to conduct design reviews with engineers from industry, and 3) using industry representatives for project evaluation. This paradigm is very successful in Grove City College's mechanical engineering capstone design program. Full control of projects remains in faculty hands, yet students work with engineers in a real-world setting. The results are successful design projects. Grove City College believes that its mechanical engineering graduates are better prepared for their careers due to this approach.

References

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