2007: Challenges to the Development of a "Real-World" Experience for the Engineering Senior - A Conflict with the Consulting Engineering Community?

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Challenges to the Development of a "Real-World" Experience for the Engineering Senior - A Conflict with the Consulting Engineering Community?

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Abstract

The Interdisciplinary Capstone Design Program in the Engineering Division at Colorado School of Mines encompasses a two-semester course sequence; with an annual average enrollment of 225 students working on 45-50 externally sponsored projects per year guided by a faculty team of eight members.

The major objective of the first semester is the preparation of a formal design proposal. During the second semester, students generally implement their design through the construction of a working prototype or prepare a design/build level bid package for the project that was designed during the first semester.

Project clients range from individuals to large corporations. Most of the corporate clients are interested in hiring our graduates. Many of these are companies that bring significant industrial problems with financial returns, or very difficult or complex problems that they have considered for several years without finding a cost effective solution. Most of these projects also come with expenses for travel and consumables for prototype or model development. Students can also work on inter-collegiate design competitions such as the Hybrid Electric Vehicle Challenge, Mini-Baja, Formula SAE or Clean Snowmobile Challenge, sponsored by the Society of Automotive Engineers, or the Steel Bridge and Concrete Canoe competitions, sponsored by the American Society of Civil Engineers, to meet the senior design requirements.

The funding sources used to cover the costs of these Senior Design project expenses include discretionary and directed gifts from corporations that hire our graduates, endowment funds from alumni, research contract support, and more recently a pre-determined and agreed upon project specific fee for a specific client-based project, payable even if the project is not completed.

Some of these project design activities have been criticized in the past by local consulting engineers as providing unfair competition in their realm of business. The area of major concern appears to be the perceptions that work done by students for no or reduced fee will take business away that could otherwise be done by professional consultants. Some cite an ethical canon, such as the second fundamental canon of the American Society of Mechanical Engineers Code of Ethics, "Engineers shall perform services only in the areas of their competence; they shall build their professional reputation on the merit of their services and *shall not compete unfairly with others.*" Closely associated with this issue is a concern of student project oversight by supervisors with professional engineer's licenses.

This paper will focus on the verbal response of engineers within the professional community to document these and perhaps other concerns. Through this paper, we hope to identify the breadth of these concerns and find a reasonable balance for these varied requirements, in addition to investigating potential ramifications for the faculty serving as advisers to student teams.

Introduction

Description of the Engineering Division at Colorado School of Mines

Within the Engineering Division, students earn a Bachelor of Science Degree in Engineering. However, they must also choose specialties in civil engineering, electrical engineering, environmental science, or mechanical engineering. The degree requires approximately 139.5 - 140.5 semester hours (depending on specialty). Detailed flowcharts of the curriculum for each specialty can be found on the Division website http://egweb.mines.edu/. Our graduates are highly recruited and hired by a wide range of companies with current placement in the 98 percentile and above six months after graduation. http://www.mines.edu/stu_life/career/employment.html

Description of senior design program

The Senior Design two-course sequence (EGGN 491, 492) within the Division of Engineering is interdisciplinary, team-based and provides students with the capstone experience of their formal education at the undergraduate level. During the past two decades, Senior Design students have pursued solutions to problems ranging from national competitions to design/build/compete a hybrid electric vehicle (more than a decade before these became commercially available) to designing and implementing potable water systems for the underserved people living in the developing world. Industry representatives desiring to hire Mines graduates also have proposed and funded various projects, some of which were later implemented by their engineering staff. Approximately 225 students per year are enrolled in the engineering Senior Design course representing 45-50 projects per year distributed among seven to eight team faculty advisors. Two of those faculty members are Lecturers (both are registered professional engineers), four are Adjunct Instructors (all are registered professional engineers) and two are tenured faculty.

Course objectives

1. Practice open ended problem solving skills through a hands-on, technical project.
2. Improve oral and written communication skills.
3. Work in interdisciplinary teams.
4. Interface with people in the "real world".
5. Develop a professional work ethic.

Definition of "Real World"

The Senior Design faculty considers a "real world" project to mean a client-based project that is addressing a design problem that someone actually has. This is as opposed to a case study or text book problem, which may have been real at one time, but has already been solved. Although students might participate in a project with a CSM Faculty sponsor/client, we expect the students to work outside of the university setting. The program is intended to be a transitional experience for the students between their academic training and their upcoming "real world' work experience. Some students make this transition naturally while others struggle with the intentional ambiguity that is presented to them throughout the program.

Project selection process

The projects need to involve open-ended interdisciplinary design problems that have multiple potential solutions. This allows the students to develop what they think will be the best solution based upon systematic engineering design techniques. We need to work with clients from the "real world" and try to achieve their expected results, without being in competition with the

engineering consulting sector. We prefer that the projects involve as many of the Division's engineering specialties as possible, namely: mechanical engineering, civil engineering, electrical engineering, and environmental engineering. Projects should also contain non-technical constraints: economic, social, legal, etc.

Team selection process

Students must write and submit a formal project application comprised of a memo specifying their top three project choices from a prepared list of projects, a copy of their resume, and a project application form. The Senior Design faculty then reviews the applications. Team matches are usually made based on the anticipated need for the number of team members from each specialty (civil, electrical, environmental or mechanical engineering), as well as the interest expressed by each student on his/her application. On projects that are international in nature, appropriate foreign language speaking/writing ability is also taken into consideration. Occasionally, projects can require a team member with expertise outside of the Division of Engineering. In such cases, seniors from other divisions are solicited to fill that need.

Topical coverage and Deliverables

During the first semester of the sequence, the students attend weekly lectures where they are introduced to systematic approaches to the design process and tools for project management. The systematic approaches include:

- -Quality Function Deployment (QFD), a technique for identifying and converting customer needs into engineering target specifications;
- -Failure Modes and Effects Analysis (FMEA), a systematic means of developing an attention to potential design safety and liability areas, along with appropriate quality control prevention measures;
- Scheduling with a Work Breakdown Structure, a Critical Path Method (CPM) Network Diagram, and a CPM Gantt chart.

In addition, there are lectures on *leadership, proposal writing, ethics, specifications, and safety*. Guest speakers are also invited to talk about various topics such as *inventing and patenting, product liability, the economics of an engineering firm, harassment in the workplace,* etc.

Students are also required to give at least one oral presentation during each of the two semesters. During the first semester, students can present at either the mid-term design review or the final proposal presentation. During the second semester, students can present at either the Societal Impacts presentation of the final report presentation.

The students' written communication skills are addressed through monthly progress reports and a special ethics assignment. They are also required to maintain their own individual project notebook.

The first semester culminates with a team written proposal and presentation to the client which defines work to be completed during the subsequent semester.

The second semester consists mostly of students working to meet the project objectives with their team faculty advisor and client. The structure is less formal with no lectures, and each project team is given the latitude to manage its project in a "learn from mistakes" environment.

Each team faculty advisor has weekly meetings with each project team to go over its schedule status and budget performance. Assignments during the second semester, in addition to the previously mentioned two oral presentations, include a 50% (of completion) project review and a final report to the client. Deliverables include a prototype and/or drawings and specifications, actual or estimated cost, and fabrication or operating procedures. In addition, the student teams must prepare a presentation for a Trade Fair. The format of the Trade Fair is that of a poster session at a professional meeting or a marketing booth for a product exposition.

Professional expectations

Students are expected to complete all of the course assignments and represent the school in a professional manner when interfacing with clients.

Funding the projects

1 Client provides funds to offset all expenses:
These projects are funded by outside clients who want to investigate their concepts through the development of a prototype or a set of information. On these type projects, students are provided with an open-ended problem statement and work toward prototype development. The client keeps the prototype or data from this project.
2 Discretionary grants made to the Engineering Division:
These are usually given to the Division with no special conditions attached by companies that hire our graduates. Lately, these companies have requested that they be allowed to select specific projects that more closely meet their company profile and interests.
3 An endowment made by alumni to support senior design activity:
We have received a generous endowment from an alumnus, Don Thorson, which has allowed us to fund more exploratory type projects or projects with educational interest to the Engineering Division or School.
4 Research grants:
As we began to explore new relationships with companies having a keen interest to hire our graduates, we have brought one project through our research and development office. However, this is an unusual path for senior design projects.
5 Project Specific Fee:
One client has agreed to pay a project specific fee to have a Senior Design team provide a budgetary, or preliminary, engineering study for a specific problem. The fee is not contingent upon the quality of the students' final product or upon expenses incurred in doing the study. It represents the perceived value of having the students' unbiased fresh approach to problems to compare with the internal thoughts of company personnel on project solutions and costs.

Rationale for this paper - concerns raised by locally based professional engineers

Several co-authors had heard occasional comments made by various engineers regarding their perception of the potential for unfair competition with local consulting engineers. Without having a forum in which this and other issues could be openly discussed with numerous people, misconceptions will continue to be held and perhaps grow into an unhealthy relationship between the professional consulting and academic communities. Therefore, the purpose of this paper is to help address this and other issues that impact the academic and professional consulting engineering communities. Dr. John Gormley, a co-author of this paper, who is also

one of the Senior Design faculty, as well as a practicing consulting engineer, wrote a letter explaining our desire to raise this issue (see Appendix A). He solicited comments from the professional engineering consulting community in the Denver metro area. The comments received were quite variable, many praising the efforts (see Appendix B) and others raising flags of concern.

The following comments were provided by anonymous consulting engineers associated with the Colorado section of the American Council of Engineering Companies (ACEC) in response to this letter:

a. Students are not Professional Engineers, or even Engineers in Training, and so should not be working on "real" projects at this stage. If the P.E. who signed their plans did not have continual, close control over their work, his/her licensure could be in jeopardy. An alternative would be to find internships at firms that can allow students to work on "real" projects. Clients might be encouraged to provide additional time for a project to allow interns to be included.

b. There is a public safety issue student's work is not closely supervised by a professional engineer. Public projects will require a P.E.'s stamp, but designs for private industry are not necessarily subject to Building department approval.

c. Oversight can be difficult when the supervising engineer has other projects going and there is a tight schedule to complete knowing that the student would need extra oversight. Also, if they were designing a real project, what if there was a problem later that involved litigation? Apart from the fact that such experience could be considered "real world" as there is, it could raise many complicating issues.

d. The main goal of the program should be to familiarize the students with the working environment (working as part of a design team) and the finished product (the contract document). This can be done without actually building a design project.

e. When doing a capstone project, it is important to create a significant focus on the client's needs and interest. Professors are not always able to do this. The clients' interest can best be served by a design team with varied levels of experience. Senior design projects usually place too many inexperienced people on a design team and so don't provide a true experience in relation to:

    - Functioning in a dynamic team,
    - Providing client service by identifying what their needs and interests are,
    - Being mentored by a Professional Engineer,
    - Understanding how their project relates to other community needs or how it may impact other infrastructure,
    - Communicating and coordinating with various agencies and the public.

f. Using consultants' current projects takes work away from engineers who potentially could be paid for the same work. For this reason, completed projects should be used for

capstone experience instead of current, ongoing projects. Some public officials already believe that engineering services are a commodity; having students do the work for free would reinforce this notion.

g. Can an inexperienced design group provide a good design that will maximize the value of the project by taking into consideration the engineering services, immediate construction, and long-term operation and maintenance costs?

h. Opportunities for internships or cooperative education provide the best benefit to students looking for additional technical experience, an understanding of what engineers actually do, and a way to enhance their resume.

These comments and questions were tempered by the following comments received from other consulting engineers (solicited by one of the co-authors, Doug Sutton).

"I encourage the competition. If there are consultants that compete for this work and don't get it because of price, that's OK. We compete on price sometimes, and at other times, we get the work because of previous relationships or history with the company. It is a good thing for the students to get these projects, and if they get it because of the low price, they will learn from the experience. The companies that hire the student contingent also must understand that this is a learning experience for the students and that the quality (and/or schedule) may suffer a bit.

The consulting industry ought to be encouraging this type of thing, because in the long run, we all gain from the experience gained by the students when we hire them."

Dennis Swann
Sr. VP
Harris Group Inc.

Also, we received a letter from another consulting engineer that related his experience as a student working on a capstone design project during his senior year at another university and the positive impact that it had on his career. This letter, written by Matthew Dole PE, is included in its entirety in Appendix B.

Statement of question
Can we provide students with a "real world" engineering design experience within the capstone design course without infringing on professional ethical constraints?

Answering the question
Applicable ethical considerations
The Code of Ethics for Engineers that is published by the National Society of Professional Engineers (NSPE) contains the following Fundamental Canons:

1. Hold paramount the safety, health, and welfare of the public.
2. Perform services only in areas of their competence.
3. Issue public statements only in an objective and truthful manner.
4. Act for each employer or client as faithful agents or trustees.

5. Avoid deceptive acts.
6. Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession.

The Codes of Ethics from the other discipline-specific professional societies; including the ASCE, ASME, and the IEEE; all parallel the NSPE Code of Ethics. It should be noted that one important individual student written assignment in our Senior Design Program involves a study and comparison of these Codes of Ethics, along with a case study analysis of a real world ethical situation. It is important to note that the students are learning how to be engineers; they are not yet even "Engineer-Interns" as defined under Colorado law. The overall goal of the Senior Design Program is to give them a good learning experience in the application of the engineering knowledge acquired through rigorous coursework, as well as teach them their ethical responsibilities as new engineers. It is the responsibility of the Senior Design Faculty, most of who are Professional Engineers, to insure that the required ethical standards are maintained on each and every project.

More specifically, as a quick example, the IEEE code of ethics, like the NSPE engineering code, addresses safety and honesty. A specific section applies to our Senior Design projects: "to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations;"[1]

Most professional engineers will readily admit that their highest level of engineering technical competence occurred as they were graduating from their university engineering program. However, to insure technical competence in specific areas, our Divisional Tenured-Faculty provide the required technical expertise to maintain the highest level of technical competence on each project. Students also consult with practicing engineers in industry to get advice on and critiques of their designs and cost estimates. Additionally, as long as we make clear to each client that students are working on the project, we have disclosed the pertinent limitations.

Finding workable solutions

The history of the senior design class within the Engineering Division at Colorado School of Mines goes back to approximately the mid 1980s when each specialty (Civil Engineering, Electrical Engineering, and Mechanical Engineering) had its own approach to design. For instance, the Mechanical Engineering option students were required to take three one credit hour Mechanical Projects Labs in which they would work on separate short-duration individual or team projects for a semester at a time. There was also a required three credit hour Engineering Design course in which the students would each work on the same project (perhaps based on a case study or representing a project that had been done before) and produce a paper report at the end of the semester.

The faculty from the three specialties formed a Senior Design committee to design a new interdisciplinary Senior Design course sequence in 1990. We were not satisfied with the discontinuous design experience that was previously available to the students and wanted to provide a more worthwhile experience for the students and for ourselves. More importantly, it was becoming clear that, in order for the United States to improve its competitiveness in the

global marketplace, significant changes within engineering education had to occur. Thus, change was strongly recommended and, more specifically, it was suggested that the most important changes would occur within the design courses[2]. For good reason, therefore, we became more aggressive in our projects, as did the manufacturing industries that hired our graduates and many other engineering schools across the country[3-7]. We sought to engage our students and industry leaders in state-of-the-art projects, which allowed all to grow substantially in the process.

We feel that many of the complaints expressed by the consulting engineering community have already been mitigated through an improved understanding of the types of projects that we undertake with students, as well as the professional oversight that exists of each project. There has been a concern voiced about the students doing work that must be stamped by a Professional Engineer (PE). In general, the stamping of engineering drawings is done for permitting and certification purposes. The overwhelming majority the projects that are done in Senior Design do not involve such permitting. In fact, we can think of only two instances in the past two decades in which a PE stamp was required on a project that our students completed. Both of them were straight forward, uncomplicated issues, on temporary structures, that had a very remote chance of impacting personal health of workers. These were analyzed and checked by one of the six Senior Design faculty who are also Professional Engineers, and the drawings were properly stamped and submitted for the applicable permits. Where the project involves a substantial scope of work, we insure that the clients are advised to have any and all of the students' work checked and certified by a properly licensed professional consulting firm.

Further to the point of client clarification and awareness of product or design limitations, student teams include "disclaimer" or "notice" statements in their deliverables as appropriate. Such statements identify the limitations of their investigations and designs. Examples follow:

- "The ground survey was performed by Colorado school of Mines students. A registered land surveyor should verify and complete the ground survey".
- "The earthworks design is limited in application because no subsurface investigation and material testing occurred. A site geotechnical investigation should be performed by a registered professional engineer, and the suggested design should be amended accordingly".

The other area that has been indicated by the consulting engineering community as cause for concern is with regard to taking away work that could otherwise be done by consultants. We have, in fact, done projects with students upon which consultants could have worked. However, we have been assured by client company leaders that these were not projects in which the clients had plans to submit a request for engineering bids. The industries have indicated that they propose these projects to our students, from a human resource recruitment perspective, because this provides them with an excellent opportunity to evaluate students as future employees while taking advantage of the breadth of knowledge base that is available from an engineering school. In most cases the scope of work for typical senior design projects is very small compared to the scope of work that most engineering firms would want to be involved with. In many instances, our projects come to us because clients cannot find an engineering firm that will to take on the work.

Some clients view the approach that a student team takes to a project as unique and very valuable. This is because the students come with open minds, free from any limiting biases that may exist within engineering firms, consulting firms, or vendors. This perspective can only be obtained from fresh, new engineering school seniors. This unique capability actually removes the student teams from head-to-head competition with practicing engineers who can not offer this same service. The clients are not looking for "permit grade" detail designs, but rather creative solutions that can be later proposed to engineering/construction firms for detail design and implementation.

In the one case where we receive a project specific fee from a client, the amount is significant enough that we take extra care to select students that we feel with provide the fresh, innovative concepts to the client. The client could probably obtain engineering services from the marketplace for equal or less but would forego the opportunity to screen our students for perspective employment offers and also miss out on their unique, "right out of school" perspective. Additionally, the client is aware that our students must be allowed to fail. Otherwise, this would not approach a real experience. In fact, all clients are made fully aware of this fundamental course requirement at the project outset. Failure to deliver a product or design does sometime occur. Students may suffer lower grades, and the Senior Design Program may lose a repeat client. Such consequences are part of the "real world" work experience.

Conclusions and Recommendations

We have worked hard within the Division of Engineering at the Colorado School of Mines over the past two decades to provide the finest capstone design experience possible for our students. This is in keeping with the development of many other capstone design courses at high-quality engineering schools around the country[3-7]. It is highly unlikely that we will revert back to relying entirely on case studies or canned design projects that are not real-time, "real world" projects. We do not generally work on projects that require a professional engineer review. This has happened with only two projects out of several hundred during the past two decades. Implementation of projects is required for the student design competitions and on a number of service learning projects that we encounter. Otherwise, student teams will work complete design projects through the feasibility study or preliminary design stage. Many of these are investigative analysis projects for the university or for outside individuals as clients. In summary, we feel that we have addressed the issues of concern raised by the professional engineering consulting community in the following ways:

1. Use of State Licensed Professional Engineers as the clear majority of Team Faculty Advisors to our student project teams.
2. Insuring that the project scopes of work are outside the interest level of most engineering consulting firms. And, if the project scope does cross this boundary, by recommending that student project outcomes are reviewed by licensed professional engineering consulting firms.
3. Insuring that our students are grounded in their ethical responsibilities as engineers.
4. By making all clients aware that these projects are being done by college students where their lack of real world experience can represent a significant limitation to the quality of the output.
5. We believe that there are ways in which the consulting industry and the university can realize substantial gains from working together on senior design projects[8]. Beyond the

obvious gains in human resource to be enjoyed from hiring the well-educated graduate, this relationship may also lead to valuable contacts with industry and detail design-build opportunities that previously did not exist.

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Appendix A

John T. Gormley
Consulting Engineer

February 25, 2007

Request for Comment and Information Regarding Engineering School Capstone Programs

Colleagues in Professional Engineering Societies:

The Colorado School of Mines (CSM) and all of the colleges/universities with ABET-accredited engineering programs include a required one- or two-semester capstone course in their curricula called Senior Design, or something similar. The CSM two-semester Senior Design Program is a step away from the traditional academic courses and a step toward the practice of engineering. Senior students are organized in teams and given assignments of projects from sources typically external to the school. The projects that are accepted by the Senior Design Program must have the attributes of giving the senior students the opportunity for (1) engaging in a substantive, multidisciplinary feasibility and design process and (2) delivering a real engineering product. The senior design teams have to produce a proposal, akin to a feasibility study, in the first semester, and a design or design/build product in the second semester. The design product typically includes an engineer's report and cost estimate, design drawings and specifications, and, perhaps, the construction of a prototype.

Some faculty members in the CSM Senior Design Program are preparing a paper entitled, "Challenges to the Development of a 'Real-World' Experience for the Engineering Senior – A Conflict with the Consulting Engineering Community?" The paper addresses the issue of aspiring engineering students doing work for no fee that could ostensibly be done by independent consulting engineers or engineering firms for a fee. The paper will be presented at the Capstone Design Conference, June 13 to 15, 2007, at the University of Colorado at Boulder.

I am assisting in this study by soliciting opinions on and experiences related to the topic from engineering practitioners in roles of responsibility with some local and national professional engineering societies. I am also asking for any information related to professional engineering society policy statements or position papers on the issue, or referrals to others who may speak with some authority on the topic.

Thank you for your consideration. As is normal, time is of the essence. Please respond at your earliest convenience, but by no later than March 25, 2007.

Respectfully,

John T. Gormley, F.ASCE

Appendix B
Copy of letter from Mathew Dole, (sent by email dated March 23, 2007).

John:

It's so long ago that I can't remember if it was called, "Capstone", but more likely something else, but at the University of Arizona where two other students and I did a "Senior Design Project" or "Capstone Project" similar to what you describe. If you want my take on the "experience", it was challenging, difficult, arduous and time consuming, but very interesting, worthwhile and beneficial to advancing the engineering expertise and experience of us three students. I don't think I could have had a better experience. I'll give you a somewhat detailed description.

Two of us worked summers (and other vacations if we wanted) for the Southern Pacific Railroad as "Technical Students", sort of an intern or co-op program. We mostly did surveying and drafting and the Railroad hoped participants in this program would keep working for them after graduation. I did for 5 ½ years. In the U of A program, students had to form their own teams, propose a project and get the engineering school to approve. It may have been a special program for selected students or optional. Our project was a realignment (a line change in RR nomenclature) of a 3-mile stretch of the SP east of Benson, Arizona to reduce the total curvature and number of curves from like 21 to 3 with acceptable increase in grades. The old alignment was designed for steam engines and minimal grading in the late 1800s and could be improved using diesel locomotives and modern earthmoving equipment.

The University accepted the proposal as did the SP who agreed to pay for certain expenses like flying the area for aerial photography. The site was bout 50 miles from campus in rough, foothill country as the railroad line climbed out of the San Pedro River Valley at Benson on its way east. We surveyed in the control for the aerial photography and plotted the contours using the University's new Kelsh plotter. We studied prospective alignments and came up with a preferred alternative. We developed an engineering report with contour maps, plan and profile drawings, cross sections, earthwork quantities, drainage structures, trackwork and a cost estimate – the whole deal. It did take a lot longer than we originally estimated. Another learning experience.

It was all received very well at the University and we received top grades. We were told the work was at the Masters Thesis level. But the best was yet to come! The SP Division Engineers office in Tucson showed our report to the President of SP on one of his trips over the line and his response was "Build it"! So our report which was really only at the conceptual to preliminary

engineering level was turned over to the engineers in the SP Tucson division office to complete the final design (and they did make excellent refinements to our work) and put out to bid.

This was completed just as I graduated and my first six months out of school, I spent on this project (the other two on my team took jobs elsewhere outside the railroad) doing surveying, construction inspection and material testing. A great experience for me and I think launched my career in transportation projects.

This is a rather long story, but the point I want to make is that these kind "Capstone" efforts can be the most rewarding and valuable experience in students 4 or more years at any Engineering school. And the value is not only to the student but to the profession. Engineering consultants substantially benefit when students graduate and come into the market with good hands-on experience. In this case and others, I have found that hands-on design and construction experience greatly enhances the book learning. I do not recall any of the railroad's engineers or local consultants complaining about the work we did on this project in Arizona or depriving them of opportunity or fees. They just wanted to hire us!

Sincerely,