Contrasting a College-Wide Engineering Capstone Design Projects Courses with a Single Department's Capstone Design Projects Courses

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Abstract: The Kate Gleason College of Engineering at Rochester Institute of Technology (RIT) offers Bachelor of Science degrees in five different engineering disciplines that include five quarters of cooperative employment experience and so-called capstone design project courses in the final academic year. Traditionally those senior design courses have been administered by individual departments with fairly discipline specific areas of interest and varied course delivery mechanisms. Beginning in 2002, a multidisciplinary senior design course was introduced that included the Electrical, Mechanical and Industrial and Systems Engineering Departments with optional participation from the Computer Engineering Department which maintained its own, rigorous and established capstone project course sequence. The coexistence of these two approaches to senior design course work has provided an excellent opportunity to observe, contrast, and leverage lessons learned from a curriculum that is very much in the development stage and one that is well established, in a fashion that should be beneficial to both programs. This paper discusses the background and implementation issues associated with these two methods of providing a capstone senior design program. It focuses on their similarities and differences in terms of course outcomes and implementations that in turn, lead to observations that may be beneficial to engineering programs in general.

Introduction: This paper briefly describes the history of capstone senior design projects courses in the Kate Gleason College of Engineering (KGCOE) at Rochester Institute of Technology (RIT). It then outlines the introduction of the KGCOE multidisciplinary capstone courses and contrasts them with the capstone courses in a single department – the Department of Computer Engineering. There have been many articles published over the years on engineering capstone design experiences. We chose to cite only three such articles that have extensive references to most of the others. The oldest is by D.L. Evans et alii [1] from 1990. Another is by Robert H. Todd et alii [2] from 1995. The third is by Clive L. Dym et alii [3] from 2006. Because this paper contrasts college-wide multidisciplinary capstone design experiences with capstone design given within a single department at RIT, we have also examined two university websites, one using a college-wide approach and the other using a single department approach: The University of Florida has a college wide program called Integrated Product & Process Design (IPPD) [4] and Professor Gary R. Swenson in the ECE Department at the University of Illinois at Urbana-Champaign has implemented a single department approach called Senior Design Project Laboratory course [5].

Background: RIT has a long tradition of co-operative education where upper division undergraduate students alternate blocks of industrial experience with traditional academic course work. To facilitate co-op, RIT's academic calendar is based on 10 week quarters with an additional week for final exams. Within KGCOE, all baccalaureate engineering programs require

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twelve quarters of academic study and at least four quarters of co-op experience for graduation. As a consequence, most engineering students require five years to complete their undergraduate degree requirements.

In the past, all of the KGCOE undergraduate engineering programs had individual department capstone courses for some time. Most started as a single 4 credit course and evolved into a pair of successive 4 credit courses in keeping with the time required to complete such projects. In the 2002-2003 academic year a pilot multidisciplinary capstone design course sequence was started in the KGCOE. Originally all of the Industrial and Systems Engineering (I&SE) students, about half of the Mechanical Engineering (ME) students, and a few Electrical Engineering (EE) students participated in this pilot project. In the subsequent years all of the I&SE, ME, and EE students participated and only a very few Computer Engineering (CompE) students participated in this KGCOE centralized course sequence. Most CompE students chose to stay with their department's individual capstone course sequence. This divergence is the basis of this paper.

2002-Present RIT KGCOE Multidisciplinary Senior Design (MSD) Course Sequence:
The Multidisciplinary Senior Design (MSD) program was conceived in 2002 with participation from the various engineering departments, as previously discussed. The goal is to enable the students to experience real world engineering problems with an emphasis placed on applying engineering design rigor and processes. Like real world design, the course encourages both individual and group accountability through teamwork activities. Student teams pool their knowledge and experience from various disciplines to solve specific design problems in an environment approximating an industrial setting including the management of their solutions, project cost and schedule. This is complemented with weekly engineering design lectures in an auditorium setting.

Prior to the start of this two quarter sequence, the Senior Design faculty compile projects from various sources including corporate sponsors, organizations affiliated with RIT, engineering faculty and in some cases student ideas. Under the guidance of one or more faculty adviser(s), student teams, usually between six and nine students, develop creative design concepts, and then perform tradeoff feasibility studies on those concepts to arrive at an optimum solution. Once the initial design concepts are selected, each team settles down to detail their design engineering activities usually leveraging their previous engineering course work and co-op experiences. By the end of the first quarter, the teams have paper designs (i.e. CAD/ ECAD drawings including schematics, software flowcharts, test plans) and are ready to start their builds. The course deliverables are integrated into their weekly project advancement in order to offer students feedback on their advancement rate. The lecture format is limited to the first three weeks. To accelerate technologies readiness, customer specifications are defined at the start of the quarter. With several projects, the teams will be given "technology solutions" as a starting point which again offers them a better opportunity to examine feasibility. This approach more closely resembles internal corporate product tracks. A single textbook which is common to all engineering disciplines was selected. Any discipline specific text will be supplemented with documents and/ or continued workshop topics. The second half of a two-quarter sequence is devoted to building, debugging and demonstrating their projects. Weekly classroom lectures continue with professional engineering topics continuing to round out ABET professional objectives. The goal is to have the teams apply these lectures to the individual team's project mission, as appropriate.

RIT KGCOE Computer Engineering Capstone Design Course Sequence:
RIT's computer engineering program had a capstone design projects course since the late 1970s when the first computer engineering degrees were awarded. Initially, the computer engineering capstone projects were crammed into one course. This evolved into a pair of capstone courses that began in the final academic quarter of the fourth year and concluded in the first academic quarter of the fifth year of the program. The first of these courses focuses on forming a project team (usually three students per team although a few projects have had only two team members), selection of a project topic, formulating a project proposal, and each team member submitting a detailed investigation of a critical project component or subsystem. (Note that the Computer Engineering student teams must formulate their own project topics subject to faculty approval.) There are also some supplementary lectures on intellectual property, project management, and a few technical topics. The second course begins with project design reviews presented to the supervising faculty and the entire class. The regularly scheduled class periods are focused on project execution, consultations, progress reports, web site preparation, and "Show-and-Tell" sessions where students bring partially completed project components for a closer review. There are also a few lecture sessions devoted to engineering ethics and entrepreneurial strategies.

In the late 1990s, prior to the start of the 2002 Multidisciplinary Program, several KGCOE departments experimented with an ad hoc collaboration on a few multidisciplinary capstone projects involving students from different academic programs on each project. Very few computer engineering students had participated in these early ad hoc KGCOE multidisciplinary design projects or in the more recent KGCOE MSD projects since 2002; instead they continued to take the capstone projects courses offered within the department for computer engineering students. One reason for this low-participation in college-wide projects was that until very recently, the college-wide projects were generally completed only a few days before graduation. The computer engineering projects courses were designed to be completed one full quarter before graduation. "Senioritis", interviewing for full-time jobs, the dual degree B.S./M.S. students struggling to complete their master's theses in time to graduate predisposed the computer engineering faculty and students to avoid participating in projects that would be completed so late.

Multidisciplinary and Computer Engineering Comparisons
As discussed previously in this paper, these two programs have different histories, motives and curriculum approaches to meet a similar mission in preparing RIT students to become engineers. The following paragraphs draw comparisons to some of the major attributes of the two programs. Specifically discussed below are: Team Structure, Funding Sources, Course Scheduling, Facilities and Course Management.

Multidisciplinary Team Structure
The multidisciplinary senior design team size of six to eight students seems ideal and represents a typical engineering development team in industry. From two or three departments, two or three students are assigned to each team. There are approximately 300 students per academic year with 40 to 50 projects. Students are guaranteed side-by-side working exposure to other disciplines.

Once the teams are established, the teams will define specific team roles including the selection of a team leader and one or more design leaders to represent the major functions. This team structure minimizes the “storming” stage since there is more individual buy-in by minimizing potential shutout condition(s). This level of organization and planning is critical during the early stages of the project to organize, schedule and define functional architecture. Three all-day workshops are utilized to manage this at the start of Senior Design I. Also worth noting is that, through the co-op program, many students had exposure to senior engineering positions; this exposure assisted the early project formation stages of where leadership is important. Once into the detailed design phase, team members migrate to specific subsystems or functions. The Senior Design faculty monitors this migration and may need to assist in the planning activities to encourage this but usually will occur through verbal expectation setting during normal weekly meetings. From a practical faculty perspective, six to eight team member size aids in managing the number of team presentations and design reviews as compared to two or three member teams.

Students have the opportunity for team leadership on a corporate sponsored project when such projects can be provided. Students have access to a wider variety of resources such as machine shops, electronic equipment, software applications and faculty across the college. Design reviews are attended by a panel of other faculty and industry people thus providing a wider perspective of comments/suggestions. Also worth noting, teams with a good GPA cross-mix usually offer the best team experiences and overall course results.

Computer Engineering Team Structure
The computer engineering design teams are usually composed of three students; on rare occasion, for slightly simpler projects, the team size is two. There is usually one faculty member supervising all the projects in a given academic quarter. The typical enrollments have been about 30 students, or 10 projects per quarter. Student teams form their own leadership structure, but the faculty member prompts individual responsibilities by requiring each team member to submit a detailed analysis of a critical project component, technology, etc. near the end of the first academic quarter. This individual detailed analysis must also contain a brief description of the detailed analysis topics being investigated by the other team members. This inclusion helps the course instructor as well as every team member to comprehend the big picture of the project. After the initial preliminary project proposal, every subsequent version (refinement) must contain a project time-line listing the major component/subsystem development, the anticipated completion date, and the team member primarily responsible for that component. Weekly project progress reports also list this project decomposition as well as the status of the previous week’s activities and plans for the coming week’s activities.

Multidisciplinary Funding Sources:
Funding sources come from grants, corporate sponsors, students and departments. The best case scenarios are grants and sponsors that support the program without explicit design missions in mind. Corporate support of the multidisciplinary program has been sufficient to support the majority the projects. This allows students to buy components, evaluation kits and hardware while still in design phase to gain first hand experience prior committing to a final design. Again, this is a similar model to industrial prototype development.

Computer Engineering Funding Sources:
Most computer engineering projects are funded by the team members themselves. Some equipment such as microcontrollers, stepper motors, motor control boards, and protoboards are available from the department. The larger and more expensive items are available on loan to the team, but smaller items such as small electrical components are given to the students. Student teams are often very enterprising at soliciting corporate donations of special technology chips for "student projects". Occasionally, another academic department will sponsor the parts for an entire project that will be used in one of its research projects.

Multidisciplinary Course Scheduling:
During pre-team formation, the faculty and sponsor defines the project mission to meet this team size. A Project Readiness Package document and associated documents defines the project and is handed over to a team during the first week of quarter. There are a number of engineering fields or tracks within this program. As an example of categories are aerospace, bioengineering, vehicle and robotics, controls and communications. These track categories may evolve depending upon student and faculty interest. Students are asked to select one of these Tracks and are then assigned to a specific team within their Track of choice. RIT is on the quarter system and most students start their MSD courses in the fall and winter of their 5th year and a few begin in the spring of their 4th year. Teams will choose in which quarter to finish.

Computer Engineering Course Scheduling:
The first in the pair of computer engineering design projects courses is usually taken in the last academic quarter of the fourth year (either spring or summer quarters). Students conduct some preliminary projects and then begin formulating their major project proposals. First each team submits a preliminary proposal for faculty review (i.e. to make a rough estimate of the project's feasibility. Students often propose projects that are far too ambitious). There are usually two other amended/refined proposals submitted at the end of the first course along with the individual detailed subsystem/component investigations. The last proposal of the first course is submitted at the last official class meeting and these graded proposals are returned during the scheduled final examination period when brief individual discussions/consultations are conducted.

Most students then leave campus for another academic quarter of coop experience. Students are strongly encouraged to do some significant work on their projects while they are out on their "nice and easy" 40 hours per week coop jobs. When they return to campus for the second course in the pair, they are required to submit an even more refined project proposal at the second class meeting. The refinements are based on their individual project contributions over the intervening coop period, or simply upon further reflection. The official project design reviews are also begun at the second class meeting and continue for another week or so. Note that the second half of the senior design project sequence is usually offered in the fall and winter academic quarters. Thus our senior design projects laboratories are utilized four quarters per year. Other course details are given elsewhere in this paper.

Multidisciplinary Facilities:
The previous individual department senior design labs have been integrated or organized into multidisciplinary labs to remain consistent with the multidisciplinary structure. With corporate interest in the KGCOE multidisciplinary senior program and as student enrollment continues to grow year after year, a significant corporate gift will allow RIT to enter the 2007 year with new corporate-like facilities for this senior design program. The new facility will integrate lab space, project integration space, team meeting rooms and project display area to illustrate the development from year to year in the theme of multidisciplinary work environment.

Computer Engineering Facilities:
During the summer of 2007, the Department of Computer Engineering will be moving into a new building addition that will provide more than a 50% increase in the department's academic and laboratory space. Included in this will be a new senior design project area consisting of a pair of connecting labs. One lab will have some elementary machine tools and more floor space to accommodate projects that have roaming autonomous vehicles.

Multidisciplinary Course Management:
Multidisciplinary program is under the management and vision of a director while department faculty collectively define and implement the program.

Computer Engineering Course Management:
The Computer Engineering program is currently under the direction of the author in Computer Engineering. However, the author sees the possibility that a single faculty "owner" could be ably assisted by other committed and well compensated faculty (i.e. possibly by enough release time from other courses) and/or very professionally mature graduate students.

Student Feedback:
The idea for this paper was not formulated until after the author began collaborating with faculty colleagues participating in the KGCOE MSD sequence. The objective of the collaboration and of this paper was to see what could be done to improve the courses. Some data had been collected for each course sequence. Because of the different forms of data collected, the author decided not to present that detailed data in this paper. The KGCOE MSD focused on-line student survey questions at the conclusion of the course. Computer engineering seniors provided ratings and comments on their capstone design experience, among other things, at exit interviews conducted immediately prior to graduation.

RIT's KGCOE Multidisciplinary Senior Design Student Feedback Summary:
A set of focused on-line survey questions was posed to the engineering students at the conclusion the Senior Design course. To gain educational benefit, the survey had the students not only reflect on their course completion experiences but also to reflect on what they viewed as their entering abilities. This course evaluation survey offered extensive write-in fields which produced specific student observations in several areas. Many of the areas of improvement were

addressed in preparation for the following academic year. In spite of MSD seeming like a great idea and a lot of hard work by a number of faculty devoted to the project, the student comments were not as positive as had been expected. The student comments have become more favorable over the previous four years of the MSD sequence's existence. Further restructuring is occurring in the current academic year with the expectation of further improvement.

RIT's Computer Engineering Graduates exit interview assessments:
Computer engineering graduating seniors provided ratings and comments on their capstone design experience, among other things, at exit interviews. Note that the vast majority of the computer engineering graduates had taken the computer engineering senior projects courses and only a few had taken the KGCOE multidisciplinary design. The computer engineering exit interviews indicated a strong positive view of the computer engineering single department capstone design sequence.

Common Observations:

(1) Although a few project teams have delivered projects worthy of being called industrial prototypes, the vast majority of projects are not. Students are generally taking three other demanding courses in addition to their capstone projects courses. Most industrial projects occupy virtually full-time work by most project team members. The time and resources available to students are usually far more limited than that available to industrial project teams. Even though virtually all RIT capstone students have already had the equivalent of a year of prior coop experience, their general professional maturity to direct, organize, and successfully deliver reasonably complex projects is usually short of what would be required. That problem is likely to be even worse for institutions that do not require all undergraduate engineering students to undertake coop work experience prior to graduation.

(2) Industrial sponsorship of projects may be difficult to sustain. Industrial sponsors generally expect industrial-grade project deliverables. As outlined immediately above, student project teams are not likely to produce such quality. Faculty often have a few industrial contacts that might produce a limited number of valuable projects, but it is difficult to generate new industrial sponsored projects year after year.

(3) Faculty mentoring time for capstone design projects is non-trivial. It is difficult for a faculty member to supervise/mentor many projects. Many institutions are not fortunate enough to have a number of professionally mature graduate students to meaningfully assist in mentoring capstone design work.

(4) Although projects and teams are formulated relatively early in the first course of the sequences, the availability of coop jobs often complicates the project schedule, especially in computer engineering when there is usually an intervening coop period between the courses. A number of students cannot obtain a single-block (i.e. one academic quarter) coop position and are required by the company to work for two successive quarters. In most cases, the other team members will rearrange their coop and course schedules to take the second course after two intervening quarters instead of one.

It would be interesting for someone to survey engineering graduates at a few points within their first five years after graduation to learn how many graduates, and from which disciplines, have significant working relationships with engineers from other disciplines. Comments and suggestions at this paper's presentation or afterward are most welcome.

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[5] ECE 445: Senior Design @ UIUC
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