

THE IMPACT OF SENIOR DESIGN PROJECT WORKLOAD ON STUDENT PERFORMANCE

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Abstract: Most, if not all, credible engineering programs have a senior design project as part of the curriculum. This capstone effort is intended to allow students to exercise four years of accumulated undergraduate education in the design of an object or a process. The Design Project (Mec E 460) in the Department of Mechanical Engineering at the University of Alberta aims to give the students in their senior year a realistic experience in all aspects of industrial design. These includes not only the academics that the students have undertaken in their degree but also the other duties carried out by a designer which could include, defining the problem, interaction with the client and documenting and communicating the solution. An increasing concern is the amount of work, time and stress undertaken by the students and the impact of this on their academic performance in this and other classes. Based on records kept by students, the teams have typical workloads of ~15 hours/person/week on average over the 13 week semester and this may be as high as 25-40 hours/person/week. A comparison however of the performance of these students to a second cohort of students who are not partaking in Mec E 460 indicates that there is little evidence of a significant impact on student academic performance. Student exit polls indicate that students are willing to make a significant time and personal commitment to courses with perceived value.

Keywords; Capstone Design Project, Design Process, Paperless Evaluation.

1 INTRODUCTION

Design is inherently a part of any engineering activity. The teaching of design concepts and processes is none the less limited within the scope of typical engineering undergraduate programs. A balance is required between the teaching of engineering science and the implementation of this knowledge into the development and design of devices and processes. The common vehicle for tying these two fields together is a senior design or capstone project course taken in the final year by undergraduates.

It has been recognized that there is significant potential for improving the benefit of such a course by making it relevant to industry and real-world practice (Todd et al., 1995, Dutson et al., 1997). The pedagogical approach to teaching design at the senior level has changed in recent years with more emphasis being placed on developing and utilizing design projects that are industry based (Incropera, and Fox, 1996, Todd et al., 1995) and follow a process (Farr et al. 2001). A number of approaches for linking the design project to industry, reported in the literature, have common themes (Todd et al., 1995, Dutson et al., 1997). Students are divided into teams or groups and are challenged to tackle an engineering design problem that has been sourced from industry. Different approaches have been documented for the interaction of the academic advisor with these groups; these include a supervisor, mentor or an academic resource (Harris and Jacobs, 1995, Marin et al. 1999). Problems of 'social loafing' and 'free riding' by students have been reported (Griffin et al. 2004) but root cause has yet to be clearly defined. The workload hours devoted to the course on a weekly basis, varies within the literature. This depends on the duration of the course (one or two semester) and the number of group members. In some cases the capstone project is the first experience the students have at an open-ended problem typical of that found in engineering design. The review by Todd et al. (1995) of courses given in programs in the US showed that 48% allocated capstone course hours of > 7 hrs/week with some programs expecting students to finish the project regardless of time commitment. Developing management skills for both time and workload can be part of the capstone project. However, there is a potential that students can focus their efforts to a single course leading to an impact on academic performance in concurrent courses.

This paper examines the impact of student workload in a capstone design course on other courses taken. To place comments into context, a description and overview of how the capstone design course is implemented in the Department of Mechanical Engineering at the University of Alberta will be presented. This is followed by a determination of the workload of students taking the course and its influence on other courses taken simultaneously.

2 COURSE DESCRIPTION

2.1 Background

The underlying philosophy of the Capstone Design Project (MEC E 460) in the Department of Mechanical Engineering at the University of Alberta is to provide the senior students with a real world experience. In 2005/2006 the program changed from a full year (two semester) course to a single semester delivered in both Fall and Winter. This was mostly in response to a significant increase in student numbers as part of a student program expansion initiated in 2002. Currently, the Faculty of Engineering has an enrolment of 1,000 students into a common first year and Mechanical Engineering receives 180-200 students into second year. Most undergraduate courses have a traditional Mechanical Engineering flavour and as such the first real opportunity for students to exercise their breadth of knowledge and experience in open-ended problems, that can cross topics and even disciplines, is in their final year through the design project. Revision of the program to take into account the implementation in a single four month semester led to the development four features around which the course was designed. These features were: 1) use of industrially sponsored projects, 2) implementation of a rigorous design methodology, 3) a paperless environment for all course submissions and 4) a consistent approach to design at all levels of the undergraduate program. The first three features are now fully implemented in to the Capstone course.

Table 1. A list of topic headings for lectures as staged through the MEC E 460 Design Project

1. Course & Design Project Introduction	13. Material Selection & Specification
2. Design Process - Phase 1	14. Conceptual Design Drawings
3. Problem Definition & Specification Development	15. Manufacturing Methods
4. Client & Team Communication	16. Design Process - Phase 2 Report
5. Industrial Design	17. Manufacturing Cost Estimating
6. Technical & Design Research Skills	18. Design Process - Phase 3 Detail Design
7. Project Planning	19. Detail Design Analysis
8. Design Process - Phase 1 Report	20. Detail Design Drawings
9. Design Codes	21. Design Presentation - Public Speaking
10. Design Process Phase 2	22. Poster Design
11. Conceptual Design	23. Design Process - Phase 3 Report
12. Conceptual Design Analysis	

2.2 Course organization

To carry out the course project work, students are divided into groups of four students and are essentially treated as a small consulting company. This group size is due to evidence of some students not fully engaging in the course with groups of five and more and a high potential for work overload for groups of three or less. These groups have weekly, one-hour meetings with a course advisor who essentially acts as a senior engineer as part of the group. The adviser takes on the role of mentor, advisor and can become involved in creative aspects of the group however all decision-making is left to the students. The role of the adviser is not to direct the project but to fill gaps of knowledge and experience that the group does not possess. This approach allows the projects to proceed in a timely fashion.

A series of two, 50 minute lectures per week are also delivered to the students. The lecture topics covered are shown in Table 1 and the intent of the lecture series is to provide information and direction to the students as appropriate in the timeline of the project. The topics and when they are delivered are also heavily linked to the design process discussed in the next section. When appropriate, these lectures are given by or incorporate a guest presenter. These can be from within the faculty of the Department or more often, design engineers

working in relevant areas in industry. The selection of lecture topics is challenging as the projects undertaken by the students are extremely varied and may range from biomedical devices to lean manufacturing to thermal systems design.

2.3 The projects and industrial sponsorship

A strong rapport has developed in recent years with local industry in providing and supporting suitable design projects for the course. The commitment on the part of industry is to set aside enough time to discuss the project with each group and to periodically field questions and critique designs. Two safety nets are built in to the course to ensure that students do not get into trouble. Each project is screened for an appropriate level of difficulty and the students have a “scope knob” that they can turn in the event that they feel that the project is growing too large for a 13 week semester. One might imagine that the student groups would take early advantage of the “scope knob” to reduce the work load but this has never been the case.

Shortly after starting the course and forming their groups the students are asked to submit a letter identifying the group members as well as first, second and third choice of projects listed on the course web site. Because the sponsors rarely want to deal with more than two groups, the number of groups working on each project must necessarily be limited. The students are encouraged to submit the letter early and are assigned projects on a first come - first served basis.

2.4 Teaching a rigorous design process

The revamp of the design courses has resulted in the implementation of a rigorous design process that is used throughout the undergraduate program. The process is broken into three phases that allow the students to focus on specific, phase related tasks breaking the larger and perhaps incomprehensible project into ‘bite-size pieces’.

2.4.1 Phase 1 - Specification development and project planning

This phase is initiated with contact between the project sponsor and the student group (without advisor). Student groups are encouraged to visit the place of business of the sponsor and the purpose of the meeting is twofold: to engage the students and the sponsor and for the students to carefully listen to the sponsor so they have a better understanding of the project requirements and scope. The student groups are usually given about two weeks to complete this task as well as any background research in the general area (review codes, standards and patents in the general area). At the end of the specification development phase the student groups submit a Design Specification as well as a short written description of the problem as they understand it. This is prefaced with the usual business communications such as a letter of transmittal and is packaged as a formal deliverable.

At the same time the students are developing specifications they are encouraged to develop a project plan. This involves identification of all of the various tasks associated with the project and an estimate (no matter how far off) of the time required and an individual responsible for each task. The division of responsibilities is not rigid but lets the group divide the project into manageable parts and helps to keep it on track. The purpose of the plan is to encourage the students to look beyond the three deliverables (phases) imposed and to make sure that they complete all of the various tasks that are necessary for the successful completion of the design. It is not important if the estimates for each task are unrealistic as this is intended to be a learning opportunity. The students are asked to revise the plan, as the course proceeds, to help develop their ability as estimators. The students are also asked to keep a running record of the hours spent in the project so that they come to appreciate that these projects have a significant cost.

2.4.2 Phase 2 - conceptual design

In the conceptual design phase the students brainstorm for possible solutions and are encouraged to sketch and create solid models of potential designs. The brainstorming sessions take place in groups (a faculty advisor might be present for some or all sessions) and the students are encouraged to suggest “off the wall” solutions - not matter how bizarre they might seem. At the end of this phase (over a period of 3-4 weeks) the deliverable

is a report detailing three concepts that will satisfy the project specifications. These must be shown in sufficient detail, and supported with sufficient solid models and scoping calculations, that the groups are convinced that each of the concepts would indeed work. The rationale behind three concepts is that if the requirements of the project are understood well enough, it should be possible to come up with multiple solutions. Once the brainstorming and conceptual analysis is complete the students have to decide which concept best meets the project specifications and should be carried forward to detail design - Phase 3. The students rank each alternative as to which concept best meets the design specifications and should go forward to detail design. Normally this involves the industrial sponsor, and indeed the design groups are encouraged to contact the sponsor and have them rank each alternative. The project plan is also updated as part of the deliverable.

2.4.3 Phase 3 - detail design

The final phase of the design course involves fleshing out the design chosen and finalizing manufacturing and material estimates. If the design process has been “front end loaded”, then this phase is used to detail the design as much as possible. At this point there is some analysis of the scope of the work and students are encouraged at a minimum to select some aspect of the project and complete a detailed design of it. This allows the students to experience all the different aspects of a complete design. A detailed design report is submitted as a deliverable and this is used as the basis for a conference style presentation and poster to be given by the student groups.

2.5 Course deliverables in a paperless environment

Each of the phases has deliverables associated with it and these take the form of a written report with appropriate tabular material and illustrations. A listing of each of these deliverables for each phase is given in Table 2. Each of these deliverables is assessed, marked and feed-back provided by two course advisors. In this way effective communication skills, through extensive and timely feedback, are developed along with the design process. It also allows a balanced view of a subjective evaluation process.

Table 2. Course deliverables at the end of each phase of the project

Phase 1 Specification Development	Phase 2 Concept Design	Phase 3 Detailed Design
<ul style="list-style-type: none"> • Business format letter to the client • Design Specification Report (1,250 words) • Design Specification Matrix • Project Schedule (time lines, GANTT chart and cost estimates) 	<ul style="list-style-type: none"> • Business format letter to the client • Abstract (350 words) • Concept Design Report (2,500 words) • Concept Specification Matrix • Project Schedule (time lines, GANTT chart and cost estimates) • Conceptual Design Calculations • Conceptual Design Drawings 	<ul style="list-style-type: none"> • Business format letter to the client • Abstract (350 words) • Design Report (2,500 words) • Design Compliance Matrix • Project Schedule (time lines, GANTT chart and cost estimates) • Detailed Design Calculations • Detailed Design Drawings • Appendices

The second and third phases have multiple deliverables of which a major component of is in written form. Every effort is made to edit and return the Phase 2 report in a timely manner so that students can review their work and incorporate any changes in development of style into their Phase 3 reports. An innovation has been to move to a completely paperless environment with submissions being typically in PDF format. This has not only removed the cost to students of duplicating reports but has also allowed them to use other tools such as animations that can be included within the PDFs. Any restriction on page length of the report has also been removed, allowing as many figures or tables as the students feel need to be included in the report. In this case, students are encouraged to document all aspects of the report and include any extra details in an appendix. Any hand calculations can be scanned and included as well. The reports, calculations, and drawings are all graded electronically. Students submit their reports and any solid models to an online “drop-box”. The PDFs are graded using a PDF editor or a tablet and pen. The word restriction on reports has been implemented both to encourage students to be concise with their writing and to also limit the amount of reading for advisors. Where appropriate, the industrial client is also encouraged to comment on the reports. Feedback from the students on the paperless environment has been overwhelmingly positive.

The final phase of the project also has other deliverables. In addition to a written report each group is asked to prepare and deliver a technical presentation to a group of peers, academic and industry judges. The presentations are a formal affair that is usually run on a Saturday near the end of the term. Since there are usually >20 design groups it is necessary to run parallel sessions in order to have everyone present in a single day. The students are encouraged to bring parents or significant others and the Department sponsors a catered lunch and coffee breaks. The presentation format is similar to a conference in that the groups each have 20 minutes to present their projects; there are five minutes for questions and a five minute change over period. All group members are required to participate in the presentation, although no one checks to see if the contributions are equal. The students take this very seriously and arrive well practiced and dressed for the occasion. The presentation is scored by the academic and industrial judges and their score is blended with the written deliverables to determine the final course grade.

The final deliverable for the course is the submission of a poster detailing each design project. The students are given a poster template, which essentially defines the size of the finished poster. It is up to them to decide what will be presented and how it will be laid out. This brings out the artistic side of some groups and the posters are innovative and unique. The department covers the cost of producing one poster per group and all posters are displayed during the formal presentations. A selection of posters from each term are framed and hung on the walls of the Mechanical Engineering building so future students can see what sort of projects have been done. The posters are graded by the course coordinators and the grade is blended with the other deliverables to assign a final grade for the course.

The breakdown of marks for each phase of the project is shown below:

The grade break down was chosen to encourage students to front end load the effort while at the same time recognize that this is a learning process. Thus the bulk of the grade is placed on the latter portions of the course (Phase III, Poster and Presentation) but there is sufficient weight given to earlier deliverables so that the students realize these are important.

2.6 *Staffing level, commitment and effort*

In a typical academic semester two full-time faculty members are involved in running the senior design project. These academics have typically a significant design background and level of experience from working in and with industry. The lectures are delivered by both faculty and the design groups are divided between each. The academics make a commitment to meet each of their 10 or 11 groups for a one hour project meeting per week during the term. The larger commitment on the part of the academic staff is the grading of the course deliverables in a timely manner. The students have only 12-13 weeks (depending on the year) to complete the designs. When assignments are submitted (Phase 1 - Specification, Phase 2 - Conceptual Design) there is a great deal of urgency to get these graded and returned to the students. Feed-back needs to be within a week so that the student groups can continue their designs. This means that the staff members must be able to set aside 20 or so hours to look over the students work and provide meaningful feedback. This is a significant time commitment during a marking week when student meetings are still held and, more often than not, academics still have another course to teach as well as all of the other duties and obligations to deal with. The total time spent on the senior design course the approaches 200 hours per staff member per term, far greater than most other traditional lecture courses. The use of teaching assistants (graduate students) was considered as a possibility to help with the grading and ease the work load. This idea was discarded as most of these people are not far removed from their undergraduate years and simply do not have a broad enough experience base to be really useful to the design groups.

2.7 Impact and Outcomes

Determining the perceived and real outcomes of a design course is not simplistic. Evaluation of the course has a component of subjectivity and the students are in their final year. Most students move on to their career so there is little opportunity to communicate post-degree to evaluate impact and outcomes.

All students are surveyed as they exit the undergraduate program and a number of specific questions relating to the undergraduate program are asked. Students are asked to rate the top four courses in the order in which they perceive the most value for their future careers. Data for the last three years is shown Figure 1 which lists the top 10 courses as ranked in 2009 with the total number of votes. In each of the last three years MEC E 460 clearly dominates. This indicates that the students perceive that there is significantly greater benefit and experience gained from completing the design project.

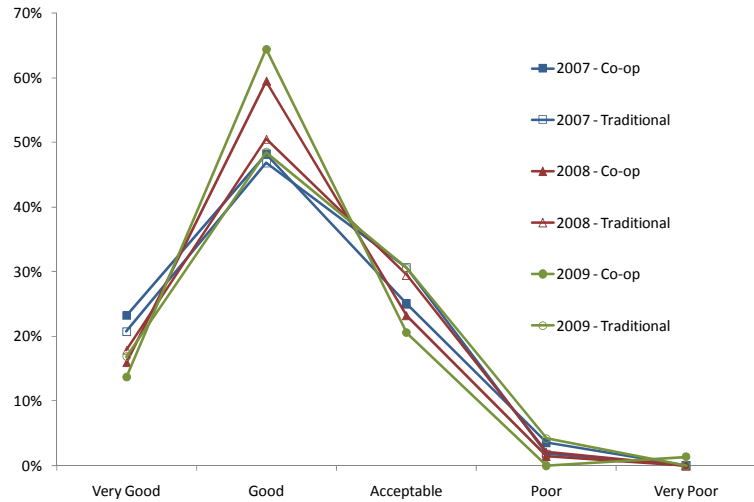
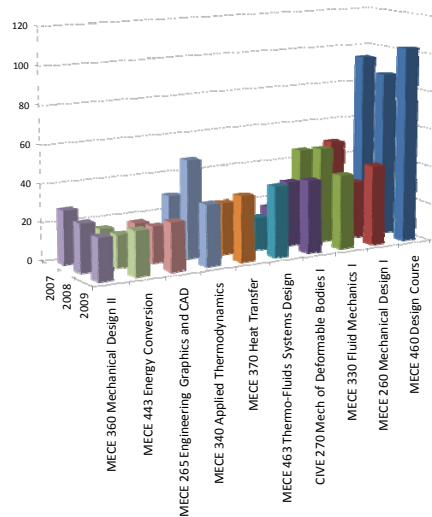


Figure 1. Listing of most valuable course as voted by students

Figure 2. Perceived level of design skills of students exiting the program.

The perceived level of design skills of students is also recorded. Data for this is shown in Figure 2 for the last three years divided into two groups of students who follow a traditional track and students who participate in a co-op program. The co-op students spend four semesters working in industry while completing their undergraduate degree. In general students feel that they have good design skills on completion of the undergraduate degree. Students that have participated in the co-op program feel that they have a higher level of design skills compared to traditional students in the same year. This would indicate that experience has an impact on the level of student confidence in the design area.

As another metric to highlight the design experience gained from the course, student performance at national design competitions can be assessed. In Canada, the Canadian Society of Mechanical Engineers (CSME) organized a student National Design Competition during their annual conference. Students are judged on the presentation and communication skills as well as good design. Typically, a student team is sent from each mechanical department in the country to participate. The following is the placing of that University of Alberta student group (group name listed) at the national competition:

- 2006 –FSAE Composite Chassis 2nd Place
- 2007 –Instrumented Speedskate 1st Place
- 2008 –Electric Vehicle Propulsion System 3rd Place
- 2009 - Extra-ocular Muscle Implant 1st Place

The continued success of student groups at this national competition indicates a consistent high level of design skills is being imparted to students during the course.

3 COMPARISON OF COURSE WORKLOAD

Given the tasks of the course outlined in Section 2 and the open ended nature of design a serious concern has developed amongst faculty members as to the impact of the workload and stress of MEC E 460 on student performance in other courses. Total time, as recorded by groups, that students spent on MEC E 460 is documented in the GANTT chart submitted with final design report. Summary information on this from all groups is shown in Figure 3 and the average across groups for each phase and overall project is shown in Figure 4. On average, students spent in the Fall 2007 (F07) and Winter 2008 (W08) semesters, 14 and 16.4 hours/person/week on work related to the course. An average expectation of workload for other courses is in the order of 8 hours/person/week which would lead to a time commitment for core study for a student carrying a full work load of 5 courses of 40hours/week. This indicates that students are spending on average, approximately double the number of hours on MEC E 460. Individual data shown in Figure 3 however highlights that in many groups, that students can spend +20 hours/person/wk on the course and in some cases as high as 40 hours/person/week, doubling the expected course workload. It should be noted here that these are hours that the students commit without provocation and indeed advisors often council groups to adjust there scope / expectations for a reasonable time commitment.

As students in a single year are divided into two cohorts, one taking MEC E 460 in a single semester and a cohort that is not, a comparison can be made between the two cohorts in a single year as they swap from participating and not participating in the design course. A comparison of average student grade point average (GPA) and course load (total academic units) for the cohorts of students the 2007/2008 academic year are shown in Figure 5. The average course load is slightly higher (4%) in the Winter semester (W08) however the average GPA is essentially the same. This indicates that the extra workload and associated stress of a group of students participating in MEC E 460 does not impact on that academic performance of the students in general.

Academic performance can also be compared across courses within a given semester relative to the performance in MEC E 460. This is shown in Figure 6 where the average GPA of other course is normalized with the average GPA of MEC E 460 for class size with >10 students enrolled. This list of courses includes core as well as elective subjects and would include students enrolled and not enrolled jointly in MEC E 460. The figure shows that students perform academically better and worse when normalized this way. The average for all courses shown is 0.99 which indicates that that the extra workload and stress has no noticeable impact on students.

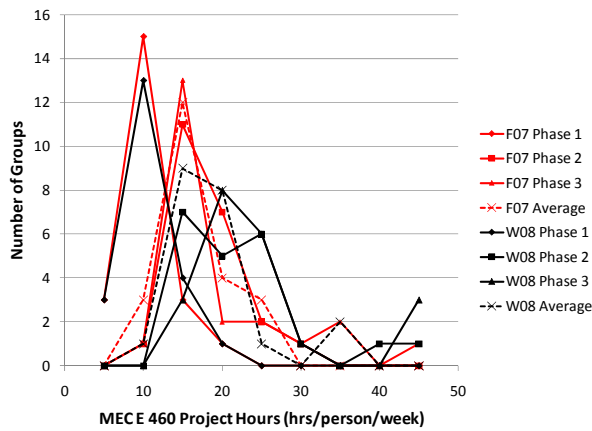


Figure 3. A histogram of student project hours for each phase of the project and overall

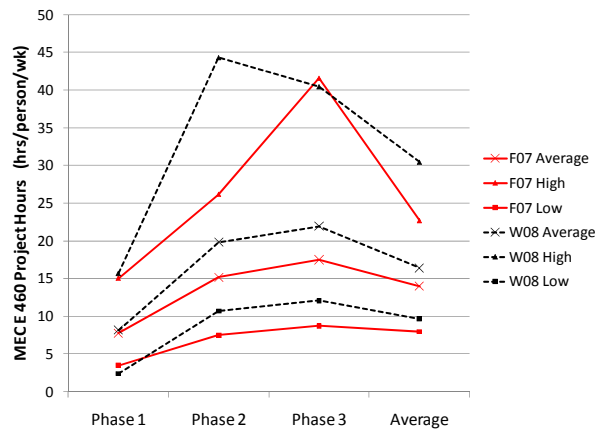


Figure 4. Average student hours per week with high and low markers

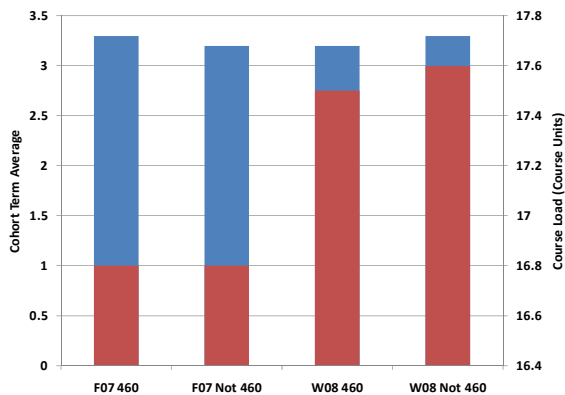


Figure 5. A comparison of student GPA (blue) and course load units (red) for cohort of students participating and not participating in MEC E 460

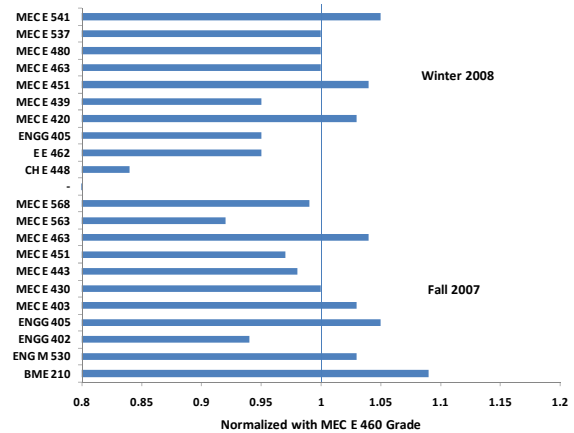


Figure 6. Average cohort GPA's scaled with MEC E 460 mark for other course taken.

4 CONCLUSIONS

A rigorous design approach has been implemented into the teaching of MEC E 460, the Capstone Design Course in Mechanical Engineering at the University of Alberta. This approach, and the open ended-nature of design, has led to a significantly larger workload compared to other concurrent courses undertaken by students. The nature of some of the course deliverables, such public speaking, meeting and working with outside professionals etc. also adds significant stress at a time when students are completing their engineering degree. There is however overwhelming support by the students for the experience that the course brings, evidence that the approach and knowledge imparted impacts student performance and that there is no discernable impact on the academic performance of students in other courses. It can be concluded that given the opportunity, students will work commit significant time and effort to such a program.

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