

Capstone Design Project - An Integrated Approach to Design

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Abstract

There are many approaches to teaching design to Engineering students. Mechanical Engineering has chosen to integrate a methodology throughout the undergraduate program in hopes that a consistent approach will make the material more easily understood by the students and easier to deliver by the academics involved. The approach presents a three stage design methodology: Specification Development, Conceptual Design and Detail Design. While this approach has been well accepted by the students it is very intensive from an academic perspective, especially at the senior level. Individual work loads approach 200 hours per term per academic involved (assuming 80 students per class) so that a strong departmental governance commitment is necessary. Industrial projects, while not absolutely necessary, allow the students to work on, and solve, real problems. Response from both the students and industry to this approach has been overwhelmingly positive. There are pitfalls as well as real costs associated with taking this approach but the effort is well rewarded in the development of more well rounded and well prepared young engineers.

Introduction

The Department of Mechanical Engineering at the University of Alberta has embarked on an ambitious plan to revamp the teaching of design at all levels of the undergraduate program. Engineering at the University of Alberta consists of a common first year with enrolment numbering about 1000 students after which the students choose a specialization subject to quotas within each department. As a result Mechanical Engineering receives 160-180 students into second year. The core undergraduate program has been mirrored (each course each term to keep class sizes less than 100) and as a result the senior design course has 80-100 students per 4 month term. The students form their own design groups (4 students per group) and are then asked to submit a written request for one of the 20-25 projects available for the term. Projects are then assigned on a "first come first served basis" putting the onus back on to the students for researching the projects and getting the requests in early.

History

The revamp of the design series came about as a result of both the students and staff being less than satisfied with both the delivery and outcomes of the existing methods. The department has experimented with various combinations of staff involvement/project sources: these at times have had up to 7 or 8 staff members involved as well as project derived from research programs or simply made up to satisfy the need. This ad hoc methodology resulted in an inconsistent approach to the teaching/delivery of design processes. The reality of teaching within a research intensive institution was that the department had no academics whose specialty was design. Thus the quality of the programs correlated strongly with the individuals involved and the experience received by the students varied from year to year. As the teaching of design/supervision of student groups is extremely time consuming there was a tendency to "share the work load" by substituting academics in these courses on a regular basis. The "changing of the guard"

on a frequent basis resulted in a lack of communication between those teaching design in 2nd, 3rd and 4th year design. This, in turn, resulted in students who were not consistently prepared to take on a major capstone group design project.

The degree of dissatisfaction with the status quo was well documented both in the annual evaluations of the design courses (students fill these out during each course) as well as exit surveys compiled by the faculty office. This is not to say that there were not successes: at times the course evaluations would be glowing. However, at times the course evaluations indicated that the students perceived that too little effort had been placed by the academic involved. Whether or not this was true was moot; the students were not happy about the experience.

In revising the program it was important to keep in mind that the design courses should be interesting and the students should be challenged. It was not the intention to make sure that the students would be “happy”, as evidenced in course evaluations or exit surveys”, only that the program delivery was consistent and ultimately of use to the students in their careers.

The revised design program incorporates four features:

- Industrially sponsored projects
- A rigorous design methodology
- A paperless environment for all course submissions
- A consistent approach to design at all levels of the undergraduate program

Industrial Sponsorship

Industrially sponsored projects provide the students the opportunity to work on real projects rather than ones conjured up by academic staff. Since there are usually 20 design groups there is a need for 15 to 20 projects each term. Since businesses have limited time to deal with student groups, the usual request is for one or two groups of students. 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.

It was initially difficult to find sufficient industrial projects and it was necessary to draw on industry contacts. As time has passed, and industry saw the very real benefit of sponsoring projects, (they essentially obtain part time employees for four months and get a preview of the next crop of students) this trend has reversed. Now calls from industry asking to sponsor a project are the norm. In deciding on project to offer one must be a bit careful, in that, after all these are inexperienced students and as such they do not yet have a good feel for the level of effort required to complete most projects. Two safety nets are built in to the senior 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” (discussed later) that they can turn in the event they feel they have “bitten off more than they can chew”.

The first contact with a potential industrial sponsor brings with it many questions about the nature of the course and projects as well as about intellectual property. Scope issues are dealt with by sending the “client” a template for a project proposal, shown in Table 1. Within this template is the usual contact info as well as a place for a brief description of the project and expected deliverables.

This is not to say that the “client” has control over the course deliverables (the same course deliverables are required for all projects) but the clients some times offer rapid prototyping, machine shop services or testing facilities so that the students can produce prototypes of their designs.

The ownership of intellectual property was initially a point of contention as the University felt that it had claims to the material and, of course, industry felt the same way. After some initial problems, and consultation with the University, it was decided that the Industrial sponsors would retain ownership of any IP, if they wanted it, otherwise the ownership would remain with the students. As a result two documents are included with each proposal package - one states that the sponsoring company will retain all intellectual property and the other states that the students will retain intellectual property. The company is asked to state whether or not they wish to retain IP on the initial project offering and if the students are not comfortable with this they do not have to take that particular project. The ownership of IP is rationalized to the students by explaining to them that the company is making a significant investment of time in the projects and they should treat this like an employer-employee relationship (or alternatively like a consultant dealing with a company). In either case the ownership of Intellectual Property would remain with the company.. not with the employee. There were some problems very early when student groups fell in love with their designs and decided they were too good to give away. Rather than letting the sponsor know of their feelings the groups chose to consult the University as to their “rights” without letting the project sponsors know what was happening. The sponsors found out about these discussions when a letter from the University appeared in their mail box asking for any and all information relating to the projects. Obviously the companies were not happy about this turn of events and the department was terribly embarrassed as a result. The inclusion of these agreements has alleviated issues related to intellectual property as all parties know beforehand who own what and act accordingly.

Table 1 - Project Specification Sheet

Mec E 460 Project Proposal Example

Objective

- Design a prototype programmable hot wire foam cutter.

Scope of Work

- Define design specifications through conversation with customer.
- Prepare three design concepts by creative brainstorming.
- Select design concept through consultation with customer.
- Prepare detailed design calculations and analysis.
- Prepare assembly and parts drawings suitable for manufacture.
- Review detailed design drawings for manufacturability.
- Develop software program to control machine.

Preliminary Design Specifications

- Input to control program to be DXF file
- Cutting area to be a minimum of 40" wide, 18" high, 24" long.
- Constant tension on cutting wire, hot or cold.
- Must be capable of making diagonal cuts.
- Variable cutting speed
- Method to clamp foam blank to cutting machine
- Fume removal
- Control program to be Windows compatible
- Manufacturing cost approximately \$750

Deliverables

- Dimensioned and toleranced assembly and parts manufacturing drawings.
- Software program
- Software program documentation
- Engineering report

Prototype Resources

- Acme will make available \$750 dollars to construct a prototype
- 100 hours of machine shop/fabrication time available in ACME machine shop
- Customer will assist with construction of prototype

Project Sponsor

Contact: Joe Blogs

Company: Acme Widget Co.

Address: 12345 – 67 Street, Edmonton, AB T6T 8Y8

Telephone #: 780 123-4567

Email address: jblogs@acmewidget.com

Available Meeting Time

A company representative is available for 4 hours biweekly to meet with student groups on our premises.

Maximum Number of Groups

Two student groups maximum

Intellectual Property Ownership

Design IP is owned by Acme Widget Co.

Design Process

The revamp of the design courses has resulted in a rigorous design process that is used throughout the undergraduate program. To ensure a uniform approach this process is integrated into 2nd, 3rd and 4th year projects. The approach uses three phases which can be emphasized or scaled back depending on the level of the students. The process is broken into three phases with the emphasis placed, as explained later, to be consistent to the ability of the students.

- Phase I - Specification Development
- Phase II - Conceptual Design
- Phase III - Detail Design

Letter of Intent

Shortly after starting the course the students are asked to form groups of four students and to submit a letter identifying the group members as well as first, second and third choice projects. Because the industrial project 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. Every attempt is made to give the groups the projects they wish to work on but at times it is necessary to give students 2nd or third choices or even go back to the groups to pick a 4th choice project.

Phase I - Specification Development and Project Planning

The Specification Development Phase is initiated with contact between the project sponsor and the student group that has chosen to work on the project. Student groups are encouraged to visit the place of business of the sponsor or alternatively book a meeting room and invite the sponsor to visit the University. 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. The student groups are usually given about two weeks to complete this task as well as any background research in the general area (such as codes and standards that may apply as well as patents in the general area). At the end of the specification development phase the student groups submit a Design Specification Matrix 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.

A sample specification matrix is shown in Table 2. This table contains a brief description of the performance requirements of the design, overall size, mass etc as well as a weighting for each. The weighting indicates how important the particular specification is to the functionality of the final design. For example, if the design must fit within a particular volume or it simply will not work the weighting would be 5 of 5. If it would be nice that the design fits within a given volume, but not absolutely necessary, the specification would be given a lower weighting. Other information that is included in the

matrix is the design authority (who has ultimate say over the particular specification: safety codes for example, ASME boiler and pressure vessel code) and specification revision history with appropriate client acknowledgement. It should be understood that the specification matrix is not invariable as it will change as new information becomes available. It is an early attempt to clearly define the problem so that students have a starting point and both the student group and the client have a good feel for where the project is headed. It also ensures that the project does not suffer “scope creep” where specifications are added as the project progresses. Legitimate changes in scope are encouraged early in the project as new information is uncovered and talks between the client and student group(s) progress. Late scope changes are discouraged as the students are under pressure, not only in this course, but also in 4-6 other courses in their programs.

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 to complete each task. It is important that they also identify an individual responsible for each one of the tasks. The responsibility is not rigid but lets the group divide the project into manageable parts and helps to keep it on track. The students are encouraged to break the projects into tasks of no more than one week duration. By making the tasks short there is a better probability that a forgotten task will be caught without disrupting the entire project. A sample project plan is included as Table 3. The purpose of the plan is to encourage the students to look beyond the three deliverables 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, in hopes that they will become better estimators of the time required. 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.

Table 2 Project Specification Development

DESIGN SPECIFICATION MATRIX Design Project: Digital X-Ray Equipment

Item #	Component / System Description	Design Specification / Requirement	Safety Factor	Design Authority	Design Importance (1-5)
1.00	Tower Subsystem				
1.10	Sub system max mass	500 kgs	-	Client	5
1.20	Manufacturing cost target	\$10,000	-	Client	3
1.30	Maintenance schedule	Monthly	-	Maintenance chief	4
1.40	Maintenance tools	Standard technician's tools	-	Maintenance chief	1
1.50	Maintenance access time	5 minutes maximum	-	Maintenance chief	5
2.00	Swivel Subsystem				
2.10	Lock actuation time max	75 ms	1.5	Client	5
2.20	Manufacturing cost target	\$7,500	-	Client	2
3.00	Control System				
3.10	Operator controls	Ergonomic design / 95% Female hand size	-	Client	4
3.20	Protection against shock	Class 1 / Class 2	-	CSA-C22.2#601.1M90 Sec 5.2	5
3.30	Water resistance	Splash Proof	-	CSA-C22.2#601.1M90 Sec 5.3	3
3.40	Method of sterilization	Citrus cleaner, bleach	-	CSA-C22.2#601.1M90 Sec 5.4	5
3.50	Mode of Operation	Intermittent	-	Client	1
4.00	Patient Support System				
4.10	Handgrip	SWL=Dead Load + Live Load	8	CSA-C22.2#601.1M90 Sec 28.4	5
4.20	Articulated Joints	SWL=Dead Load + Live Load	8	CSA-C22.2#601.1M90 Sec 28.4	5
4.30	Support arm connection	SWL=Dead Load + Live Load	8	CSA-C22.2#601.1M90 Sec 28.4	5
Notes	Design Importance Score	5 - Essential or required feature / 1 - Optional requirement 10 - Meets requirement in all respects / 1 - Does not satisfy requirement			
5.00	Revision History	Revision Date			Initial

Table 3 Project Timeline Estimates

ID	Task Name	Duration	Start	Finish	Baseline Work	Baseline Cost	Actual Work	October							November				
								9/11	9/18	9/25	10/2	10/9	10/16	10/23	10/30	11/6			
1	ACME DESIGN PROJECT	23.45 days?	Thu 9/29/05	Tue 11/1/05	196 hrs	\$14,460.00	0 hrs												
2	Phase 1 - Project Planning & Spec Development	23.45 days	Thu 9/29/05	Tue 11/1/05	196 hrs	\$14,460.00	0 hrs												
3	Assemble design team	0.25 days	Thu 9/29/05	Thu 9/29/05	8 hrs	\$600.00	0 hrs												
4	Prepare first draft of project schedule	1 day	Thu 9/29/05	Fri 9/30/05	8 hrs	\$600.00	0 hrs												
5	Review project descriptions	0.5 days	Fri 9/30/05	Fri 9/30/05	4 hrs	\$300.00	0 hrs												
6	Contact potential clients	2 days	Fri 9/30/05	Tue 10/4/05	16 hrs	\$1,200.00	0 hrs												
7	Choose project	1 day	Tue 10/4/05	Wed 10/5/05	32 hrs	\$2,400.00	0 hrs												
8	Project review meeting with client	0.8 days	Wed 10/5/05	Thu 10/6/05	32 hrs	\$1,920.00	0 hrs												
9	Meeting w/Project Advisor	0.4 days	Thu 10/6/05	Thu 10/6/05	16 hrs	\$1,440.00	0 hrs												
10	Product / project research	4 days	Thu 10/6/05	Wed 10/12/05	64 hrs	\$4,800.00	0 hrs												
11	Write first draft of product specification	1 day	Wed 10/12/05	Thu 10/13/05	16 hrs	\$1,200.00	0 hrs												
12	Internal review of product specification	1 day	Thu 10/13/05	Fri 10/14/05	0 hrs	\$0.00	0 hrs												
13	Meeting w/Project Advisor	0.5 days	Fri 10/14/05	Mon 10/17/05	0 hrs	\$0.00	0 hrs												
14	Product / project research	3 days	Mon 10/17/05	Thu 10/20/05	0 hrs	\$0.00	0 hrs												
15	Review product specifications / project scope with client	0.5 days	Thu 10/20/05	Thu 10/20/05	0 hrs	\$0.00	0 hrs												
16	Product / project research	2 days	Thu 10/20/05	Mon 10/24/05	0 hrs	\$0.00	0 hrs												
17	Revise product spec / project scope	1 day	Mon 10/24/05	Tue 10/25/05	0 hrs	\$0.00	0 hrs												
18	Revise project schedule	1 day	Tue 10/25/05	Wed 10/26/05	0 hrs	\$0.00	0 hrs												
19	Meeting w/Project Advisor	0.5 days	Wed 10/26/05	Thu 10/27/05	0 hrs	\$0.00	0 hrs												
20	Client approval of product spec / project scope / schedule	0.5 days	Thu 10/27/05	Thu 10/27/05	0 hrs	\$0.00	0 hrs												
21	Prepare Phase 1 Report	2 days	Thu 10/27/05	Mon 10/31/05	0 hrs	\$0.00	0 hrs												
22	Submit Phase 1 Report	0.5 days	Mon 10/31/05	Tue 11/1/05	0 hrs	\$0.00	0 hrs												
23	Phase 1 Complete	0 days	Tue 11/1/05	Tue 11/1/05	0 hrs	\$0.00	0 hrs												
24																			
25	Phase 2 - Conceptual Design	1 day?	Thu 9/29/05	Thu 9/29/05	0 hrs	\$0.00	0 hrs												
69																			
70	Phase 3 Detailed Design	1 day?	Thu 9/29/05	Thu 9/29/05	0 hrs	\$0.00	0 hrs												
94																			
95	Design Poster	1 day?	Thu 9/29/05	Thu 9/29/05	0 hrs	\$0.00	0 hrs												
103																			
104	Oral Design Presentation	1 day?	Thu 9/29/05	Thu 9/29/05	0 hrs	\$0.00	0 hrs												
117																			
118	Final Design Report	1 day?	Thu 9/29/05	Thu 9/29/05	0 hrs	\$0.00	0 hrs												

Phase II - Conceptual Design

In the conceptual design phase the students brainstorm for possible solutions and are encouraged to sketch and create solid models for 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. The purpose of these sessions is to stimulate thought and to explore areas that might otherwise be missed. 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 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. If the students are having difficulty coming up with three unique concepts (three colors does not equate to three concepts) they are encouraged to solicit the help of the faculty advisor or the industrial sponsor. In some cases the project has been over constrained and as a result there is seemingly only one solution. If this is the case the students are asked to identify the constraint that is causing problems and to discuss this with the sponsors. More often than not the constraint that causes problems is not a hard physical constraint but is something that was thrown in the mix in order to get the students started. If this is the case the students ask formally for a relaxation of the constraint that is governing (some times this is not possible due to a physical constraint) and the sponsor will sign off on the revised specification matrix. If the constraint is actually a hard one (cannot vary) then the students are taken through another brainstorming session with the faculty advisor involved and this usually resolves the impasse.

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 to rank each alternative using a rational methodology such as Pugh’s method and from the ranking make a recommendation 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. Time limitations do not allow for delays of more than a few days so the groups are asked to make a recommendation, support the choice and move on to detail design.

Phase III - 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”, meaning that the conceptual design phase was done in some detail, this final phase really only requires “dotting the i’s and crossing the t’s”. The reality is that as much as the students are encouraged to do the work up front there is a tendency to procrastinate and leave things until the due date looms.

Course Deliverables

Each of the phases has deliverables associated with it and these usually take the form of a written report with appropriate tabular material and illustrations. In this way effective communication skills are developed along with the design process. The initial deliverable is quite modest (the students do not realize until later that the more effort that goes into the specification development the easier time they have later) and consists of:

- Business format letter to the client
- Short description of the project background
- Table of specifications
- Project plan (time lines and cost estimates)

The second phase of the project has a similar set of deliverables:

- Business format letter to the client
- Short description of the project requirements
- Discussion of three concepts (with illustrations)
- Design evaluation and explanation
- Supporting design calculations
- Solid models or design drawings.

The third and final phase has multiple deliverables associated with it and is tied to the design presentations and project posters. 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 very near the end of the term. Since there are usually approximately 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 break down of marks for each phase of the project is shown below:

- Letter of Intent (students submit letter indicating 1st, second and 3rd choice projects)5%
- Phase I - Specification Report 15%
- Phase II - Conceptual Design Report25%
- Phase III - Detail Design Final Report 35%
- Poster10%
- Presentation10%

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.

The final report is limited in the length of the main body (2500 words) but is not restricted in the number of figures and tables. The short length is intentional in order to force the students to be clear and concise and to use illustrations rather than attempting to describe complex systems in words. The appendices, which may contain sample calculations, drawings and manufacturers data sheets (if any), are not limited in length. The students are aware, however, that the level of our patience is inversely proportional to the number of pages we have to read.

The final deliverable for the senior 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 really brings out the artistic side of some groups and the posters are a wonder to behold. The department picks up 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.

On Going Paperless

The paperless environment was developed in response to student concerns over the increasing cost of producing reports/figures for the courses. At one point groups were asked for four copies of each deliverable; two for the instructors, one for the industrial sponsor and one for the archives. Students commented that they were spending upwards of \$500 in duplicating costs - obviously not an acceptable situation. As a result the departments IT people were approached with the problem. The IT group came up with a custom web based drop box system which allows students to submit assignments from any place using a web browser interface. The assignments are graded electronically, either using a desktop and pdf editor or a tablet and pen. The marked up assignments are then emailed back to each member of the group, as well as the project sponsor, so everyone has a copy.

Going paperless is not without a cost and there have been some bumps in the road along the way. The students are asked to scan calculations, data sheets and the like, turn them into pdf files and put them together into single documents. When the paperless environment was first introduced the course instructors were less than careful about informing the students about appropriate naming conventions. As a result the very first look at the drop box directory revealed 20+ files named "Phase I - Project Specification". The students have subsequently been asked to choose a group name or at the very least use the initial of the group members to identify all files submitted. Since the sample calculations may number many pages the department has had to purchase robust document scanners with feeders so that students do not spend large amounts of time scanning single sheets.

Feedback from the students on the paperless environment has been overwhelmingly positive. Aside from a few glitches with fugitive documents the transition has been relatively painless.

This could not have been done without the tireless support of our IT personnel who have made sure that all of the computer labs in the department (there are three for about 600 students, total 90 seats) have the appropriate software (ProEngineer, MS Project, pdf printer drivers) as well as ensuring that the drop box features of the departmental servers is fully functional.

Level of Effort and Staffing

Compared to a traditional lecture course with a midterm and final examination as well as regular assignments the level expected of the students is significant. The course has one lecture hour (will be extended to two next year) and the students are expected to work 8-12 hours per week (per student) for the 12-13 week period. Thus the students will commit between 384 and 576 hours for this course. The students are encouraged “front end load” this effort and to put the bulk of the effort into specification development and conceptual design rather than leaving things to the end. The cost of making design changes throughout a project is illustrated in the lectures and the students come to realize that late design changes are very costly and time consuming.

Running a series of design courses in this manner is expensive both in actual dollars spent as well as staffing. The senior course has two full time academics associated with it but the department commitment extends well beyond that. Each of the academics involved makes a commitment to meet with 10 or 11 design groups for a one hour period each week during the term. The intent of the meetings is not to tell the students what to do but rather to provide guidance and be a resource. To keep with this theme the meetings are to be organized and run by the student group - not the academic. The purpose of the weekly meetings is to ensure that the projects stay on track and that there are no “deal breaker” things missed in the designs. This has happened in the past, simply because the students are inexperienced, and may assume that things work in one manner when in fact they work in a totally different manner.

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 I - Specification, Phase II - Conceptual Design) there is a great deal of urgency to get these graded and returned to the students. The students cannot wait for weeks for the feedback, but need it within a week or so to continue on with the 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. While this may not seem like much - it is huge! During marking week 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 term, far greater than most other traditional lecture courses. The use of teaching assistants (graduate students) has been considered to help with the grading and ease the work load. This 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.

As the designs progress and the students are asked to estimate the costs of manufacturing the emphasis shifts to the machine shop personnel. A full complement of machinists and technicians are available to the students (by appointment) for consultation. If students want to explore different methods of manufacturing an object or need help with material selection they make an

appointment with one of the shop people and may spend a couple of hours going over the design to ensure that: the object can be made as drawn and the design has not suffered “racing hole syndrome”. What is meant by this is that the design software used by the students makes it easy, and a few mouse clicks, to turn a workable design into a very expensive, hard to manufacture design. Students are often surprised by this as they assume “if I can draw it- they can make it”. While this is largely true there is a significant cost associated with this practice. The machine shop personnel simply make sure that the students understand the implication of these “simple mouse clicks”.

The departmental contribution continues as the projects come to a close in that all parties are brought together for the design presentations (student groups, industrial sponsors, academics, guests). As was stated earlier this usually takes place on a Saturday and the department sponsors a luncheon as well as coffee breaks and goodies. The cost of doing this easily runs \$2000-3000 depending on the caterer and the menu. The feedback from the students, significant others, parents and industrial sponsors has been overwhelmingly positive with respect to this event. Word of mouth among the industrial sponsors has led to requests to be included so there is little need to coerce anyone into judging.

Conclusion

In order to present a consistent design methodology to our undergraduates Mechanical Engineering has attempted to bring the three stage design method into each increasingly complex design course. At second year the students do not really have the tools to do a complete analysis so the emphasis is placed on the specification and conceptual design stages. With increasing competence the students are able to tackle more difficult problems and the emphasis on analysis and drawings increases. At the end of the fourth year the students are expected to deliver a solid design with sufficient backup analysis that the device or system could be manufactured with a little additional refinement.

The implementation of a sequence of design courses has meant that by the time the students reach 4th year they know what to expect, are reasonably proficient in project planning and management and their communication skills are polished.

This sort of design stream cannot be undertaken without a significant level of support from the departmental governance. Successful implementation involves both the academic and technical staff and consumes a great deal of departmental resources. It is the belief of the academics delivering the design stream that this approach, coupled with real projects from industry, provides the best experience for the students and results in better equipped new graduates.