A Just-In-Time Approach to Teaching Senior Design

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Abstract

The subject of this paper is the approach used to teach the senior design project course in the Mechanical Engineering Department at Michigan Technological University. The primary objective in the development of the required two semester senior design sequence was to insure a positive experience in mechanical engineering design while eliminating the procrastination that can be prevalent in long term projects. The approach taken is the "just-in-time" introduction of lecture topics pertinent to the development of the students' engineering design projects. Each of the major topics covered in class also involves an assignment and mini-report due within a short period of time after the related lectures. For example, the first assignment includes providing the course instructor and the project advisors with information concerning how each team is organized along with project specifications and goals. The second assignment, which follows lectures concerning patents and sources of information, requires a project "initial" background information and patent search report. Complete lists of the assignments and associated lecture topics are included in the paper.

One consequence of having a sequence of mini-reports completed during the semester, besides forcing the students to systematically make progress, is that the job of writing a final report is a much easier task. The student teams are able to update and edit their mini-reports into a comprehensive and complete final report without having to spend inordinate amounts of time on the task. Students have responded very favorably to the "just in time" organization of the senior design course. The system used in the course resulted in the minimization of procrastination problems and made the completion of good quality professional design reports a much less daunting task. A major result of the course organization is also the fact that the material presented in class is immediately relevant to the project work of the students.

The paper includes details of how the first semester senior design project course was conducted, as well as examples of the types of design projects included in the course. Additional information is provided concerning the second semester course, which involves topics such as an introduction to design optimization, Failure Modes and Effects Analysis, and the design and implementation of engineering experiments as related to the testing of design prototypes. The final results of the two-semester senior design sequence includes the development of working prototypes, the completion of professional quality written and oral reports, and the production of an informative and attractive poster by each team.

Introduction

Michigan Technological University changed from a quarter based system to semesters effective the fall of 2000. Prior to making the change a considerable amount of work went into planning and developing curricula in the different colleges and departments across campus. During this period in the late twentieth century, 1998 and 1999, the Mechanical Engineering-Engineering Mechanics (ME-EM) Department reviewed the mechanical engineering programs at more than twenty well known universities across the country and held numerous meetings to discuss proposed changes in the curriculum. Meetings were also held with students to provide information concerning the transitions to semesters for students who were approaching their senior year. At one such meeting a third year mechanical engineering student expressed his concerns regarding the senior design course in a 15 week semester versus a 10 week quarter. The student's main point was that many senior design students he knew procrastinated and did most of their work at the last minute near the end of the quarter. He wondered what the department would do to prevent this from becoming an even more serious problem in the longer semesters. As a result, at least in part, to this student's concerns much thought was put into developing an approach to senior design that would minimize procrastination while encouraging students to do the technical work necessary for the successful completion of challenging senior engineering design projects. This paper presents information concerning the senior design project course organization and delivery with special emphasis on the mini-report assignments due at specific times during the semester.

While considering the change from the quarter system to semesters the ME-EM Department decided to place considerably more emphasis on design in the new curriculum. Under quarters the department required that all ME students complete a one quarter three credit senior design project course. The new requirement approved by the faculty requires that all students satisfactorily complete a two-semester sequence of three credit courses, MEEM4900 and MEEM4910. This new commitment to design was based on an interest in providing students with a significant experience in engineering design from problem definition and concept development to the construction and testing of prototypes. It was also based on the desire to provide the majority of the mechanical engineering students with the opportunity to work on meaningful industrially sponsored projects for which less than two semesters of time would be inadequate.

Background

While developing the new semester based mechanical engineering curriculum it became evident that by requiring an additional 3 credits in the design sequence the department was making a commitment to design that would require the involvement of additional faculty and the development of suitable facilities. It would no longer be possible for one or two faculty alone to shoulder the responsibility of soliciting projects, advising students, evaluating design results and determining individual grades. Consequently a senior project coordinator was hired to solicit suitable projects and a system was developed to get faculty involved as technical project advisors and managers. The system is still in the process of evolving but happily has resulted in some very successful projects; both externally funded and internally funded. The latter usually related to faculty research, in particular for newer faculty, or for design competitions sponsored by either ASME or SAE.

The majority of the mechanical engineering programs in the country require a one-semester senior design project course. This is understandable considering the cost and other difficulties involved with sustaining projects for a full academic year with the expectation that the majority of the projects will result in the construction and testing of hardware, i.e. design prototypes. It is hoped that this paper will provide faculty and administrators at other universities some insights into at least one way of organizing a two-semester sequence of senior design project courses.

Course Documentation/Communication Requirements

A variety of different forms of written communications are required. These help to both insure progress and provide records of work completed. Oral progress and final reports are also an integral part of the course. The following sub-sections provide information concerning each of the different course communication requirements.

Design Notebooks

Each senior design student is required to document all of their design work, including computer modeling and design/analysis in a design notebook and/or portfolio. This means that records must be kept following guidelines based on requirements for engineering notebooks used in industry, complete with dates, signatures of the student and witnesses and adequate written explanations similar to providing comments in software. Students are advised to emphasize use of appropriated engineering technology, and to document this work, as opposed to making design choices on an arbitrary basis.

Progress Reports

Student teams, normally of 3 to 5 students each, are required to meet with their faculty advisor at least once every two weeks. Most teams actually meet once a week for an hour with their advisor, at a time convenient to all participants. At these meetings students present oral progress reports, turn in weekly activity (progress) reports and discuss their projects, with the faculty advisor serving as a resource person and manager. Students working on industrially sponsored projects participate in regular conference calls and/or video-conferencing sessions with their sponsors. These are usually held on a weekly or biweekly basis. The department has two rooms equipped for video conferencing, one reserved primarily for senior design students, and five rooms with conference call capabilities.

Models and Prototypes

During the first semester students are required to develop computer models and proof-of-concept hard models for evaluation. Some teams actually build fairly sophisticated prototypes in the first semester, dependent on the specific project requirements, but most don't get to this stage until the second semester. The faculty advisor completes an evaluation of these models with the course instructor and project sponsor. This information is included in the determination of project and individual grades.

Midterm Oral Reports

A technical plan or proposal is presented sometime just past the middle of the semester. A committee of faculty evaluates these with contributions also made by students. Feedback is then provided to the student teams as soon as possible so that they can modify their approach if necessary based on the comments and suggestions/requirements provided. These reports serve several purposes including 1) to provide a milestone to help maximize the output of the students, 2) to help insure that all projects include the appropriate engineering/technical work at an acceptably high level, and 3) to give the students experience with formal oral presentations. The latter results in noticeably improved final presentations at the end of the semester.

Final Written and Oral Reports

The final reports, both oral and written, must satisfy a list of requirements presented to the students early in the semester regarding content and formats. A committee of faculty and industrial sponsors evaluates the oral presentation, with input also provided by students. The faculty advisor and course instructor grade the final written report, but also seek comments from sponsors whenever possible. A major consideration in the grading is the technical work done as a part of the design process. This includes the quantity and level of work as well as evidence of creativity and originality.

Poster Sessions

Mid-term and final report poster sessions are held in the second semester course (MEEM4910). The posters are later displayed in the Design Creativity Center; an area on the second floor of the ME-EM building that is reserved for use by senior design students. The posters must follow guidelines adapted from those required for NSF poster sessions. The size requirement is 48 inches (1.22 m) wide by 36 inches (1.22 m) high. The guidelines include recommendations regarding font size and the inclusion of graphics.

The Just-In-Time Approach (Milestone Requirements)

The main purpose of this paper is to present the approach used to minimize procrastination and help enable students to put together professional quality final reports without requiring a binge effort at the end of the semesters. This approach was developed in response students' comments and concerns prior to the change from quarters to semesters. It is also the result of lessons learned during more than twenty years of teaching senior design and advising student design teams.

The approach developed was one of requiring a series of "mini-reports" from each student team. These reports are each due soon after the related material was presented in class. For example each team must submit a Team Organization and Project Specification mini-report by the end of the second week of classes. This forces the student to meet as soon as possible in the semester to discuss their projects and develop quantitative design specifications with performance requirements and goals. A list of all the mini-reports required during the 15 week first semester (MEEM4900) is provided below.

Mini-Report:	Week Due:
1. Project Preference Report	1st
2. Team Organization and Project Specification	3rd
3. Patent and Background Information Search	5th
4. Initial Concept Development Report	6th
5. Concept Generation and Evaluation (H. of Q.)	7th
6. Technical Plan Oral Presentation	9th
7. Design for X and Safety Report	10th
8. Ethics Problem Discussion Report	11th
9. Project Cost Report and Business Plan	12th
10. Team Organization Plan for Final Reports	13th

All of the mini-reports are due soon after the topic associated with the report is presented and discussed in class. The first mini-report is due the end of the first week and consists of a statement of interest in the projects that were presented and explained in class. Information about the projects is also posted in the ME-EM Building and is available on the Department's web site. Besides a statement of preference for first, second and third choices this report must include a resume with information relevant to project placement highlighted.

Guidelines are provided to the students concerning the formats and length limits of each of the reports. The ethics problem discussion report deals with responding to scenarios of fairly complex and realistic ethical dilemmas. The project cost report, report number 9, is required to include the costs associated with conducting the engineering design work associated with each project based on typical salary levels for practicing engineers plus overhead and real costs related to development of any models or prototypes built. This report must also include the costs associated with production of a working prototype as well as costs that would be incurred if a "quantity" of the designs were produced. For example if the design project involves designing a special laboratory test apparatus the students must determine the cost of producing one working prototype and the cost of producing a reasonable number of the test apparatus that could possibly be sold to interested research labs or universities. The purpose of this exercise is to make the students aware of the many considerations related to quantity production as opposed to simply determining the costs of components with no quantity discounts. This also makes the students more aware of the need for process planning and careful development of manufacturing plans for quantity production of parts.

The course instructor and the graduate teaching assistants who are assigned to help with the senior design courses grade all of the mini-reports. The results from these evaluations are communicated with the faculty members who serve as project advisors. The advisors are then able to provide guidance to their teams regarding any possible deficiencies. The goal here is to have fair, impartial and consistent grading standards applied to all the student teams. This can be a considerable challenge when there are on average about 40 design teams per year, with about 30 during the Fall and Spring semesters and 10 during the Spring and Fall semesters.

Lecture and Study Topics

A study of the list of mini-reports presented in the previous section of this paper will identify many of the lecture and study topics of the MEEM4900 course. A complete list of the course topics is presented here, followed by a list of the topics included in the second semester MEEM4910 course. The course meets twice a week for 50-minute sessions on Tuesday and Thursday afternoons.

Week	Topic(s)
1	The Product Design Process and Presentation of Projects
2	Need Identification and problem Definition, Design Notebooks, QFD and Design Specifications
3	Team Behavior and Tools, Planning and Scheduling, Progress Reports
4	Information Sources, Intellectual Property and Patent Searches
5	Patent Costs & Foreign Patents, Concept Generation and Creativity
6	Introduction to Axiomatic Design Concepts, Concept Evaluation Methods
7	Embodiment Design, Human Factors in Design and Design for X
8	Modeling and Simulation in Design, FEA, Rapid Prototyping
9	Materials Selection, Materials Processing, DFM and DFA
10	Design for Reliability and Safety, Legal and Ethical Issues
11	Ethical Considerations in Design, Cost Evaluations and Estimates
12	Engineering Design Proposals, Detail Design and Bills of Materials
13	Communicating the Design, Written and Oral Communications
14	Course Discussion and Course Evaluation

The text used in the course is Engineering Design, Third Edition by George E. Dieter, McGraw-Hill, Boston, 2000. A Guide to Writing as an Engineer by David Beer and David McMurrey, John Wiley and Sons, Inc., New York, 1997 is also required. In addition the book Patent Fundamentals for Scientists and Engineers, Second Edition, by Thomas T. Gordon and Arthur S. Cookfair, Lewis Publishers, CRC Press LLC, Boca Raton, 2000 is used as a reference. The combination of these three books covers the majority of the topics emphasized in the course. Students are also encouraged to make good use of other references that are pertinent to their specific project needs.

The second semester course, MEEM4910, has a much shorter list of topics because this course emphasizes completion of project work. Consequently this course only meets for one 50-minute session each week, on Tuesday afternoons. The list of topics for the second semester course is provided below.

Week	Topic(s)
1	Project Reorganization, Schedule Evaluation and Revisions, Reassessment Of Technical Work Planned
2	Computer Modeling and Detail Design, Planning CAE Activities
3	Dimensioning and Tolerancing, GD&T, DFM and DFA Reminders
4	Introduction to Optimization Methods, Quality Assessment
5	Optimization Continued, Multivariable Search Methods
6	Failure Modes and Effects Analysis (FMEA)
7	FMEA Continued, Failure Analysis
8	Midterm Poster Session Reports
9	Failure Analysis Continued, Documenting Failures
10	Design of Experiments, Planning for Prototype Testing
11	Documentation of Experimental Work, Design of Data Sheets
12	Communications Reminders for Oral and Written Reports

There are no class meetings during the last three weeks of the semester so that the students can concentrate on their projects without any extra distractions. Of all the topics covered in the second semester the one that seems to be the most problematic is that of doing careful engineering experiments to test prototypes. This is in part due to inexperience and perhaps because the students are at a point where the "light at the end of the tunnel:" is so powerful that attention to details in the area of experimental work is too difficult. More emphasis related to this topic is probably needed in other courses earlier in the students' academic careers. A logical place for this might be the required engineering laboratory course. In an attempt to point the students in the right direction some examples of professional reports dealing with experimental work are made available to the students as good examples of how to report experimental work properly.

Poster Sessions

The midterm progress report in the second semester project course is in the form of a poster session. Professional quality posters are printed following guidelines provided in class. The first semester that this was required a poster that was used at a NSF poster session by several MTU faculty was used as an example. The value of having at least one good example to look at cannot be over emphasized here. Now that there are dozens of posters in our collection from the past couple of years the students have more than enough examples to guide them. The quality of the posters has consequently improved steadily since the first posters were submitted. Some posters still do not however include sufficient technical content. In some cases token finite element results are included in an attempt to demonstrate that "technical work" was completed. Many of the posters however are excellent, both aesthetically and in technical content. The posters are all plotted using electronic documents primarily from the Frame-Maker software. They are then mounted on stiff sheets of backing material to facilitate displaying on easels.

A final report poster session is held at the end of the second semester. The students are consequently able to make use of midterm evaluation results as a basis for improvements. The evaluations are completed, both at the midterm and at the end of the semester, by a panel of judges made up of faculty members and graduate students. Undergraduate students who are currently enrolled in the first semester project course also make a contribution here. They compare all the current posters to one from a previous term and complete Pugh chart forms. These results as well as the evaluation "grades" and comments from the panel of judges are provided to the student design teams.

The poster sessions have become a popular activity on campus. Students, staff and faculty from the ME-EM Department and other departments on campus come to see the posters and ask questions of the student design teams. In addition students from several local high schools are bussed to campus to see the final posters and interact with the design team members. Besides the posters prototypes are put on display at the end of the semester. This event is part of the Senior Design Day activities held every spring.

Example Design Projects

There have been around one hundred different projects in the past two years. About 75% of the projects have been provided and sponsored by industry. Non-industry projects include some special test equipment that was designed and built for use in thermal-energy labs in the department. One of these demonstrates the use of fuel cells as a source of energy. Another demonstrates the principles of combustion. Several other non-industry projects were in answer to competitions sponsored by ASME and SAE. These include the mini-cargo plane and human powered vehicle design competitions. The industrially sponsored projects include the design and building of special fixtures for assembly of mechanical products and improved designs of some existing products. One of the latter is a "stream sweeper" used to improve the quality of streams so that they can support more trout. A four-wheel drive hand (arm) powered vehicle was also designed and built.

A large variety of projects have been completed in the last two years and 30 additional projects are currently underway. Also around 10 new projects were started this spring semester. One of the challenges that arises due to the variety of projects is that of insuring that all of the design teams have roughly the same level of challenge. This requires considerable effort by the course instructor and faculty advisors. The industrial sponsors and contact persons must also be included in the process so that the students receive consistent messages about the requirements and expectations of their projects. It helps to carefully screen projects ahead of time to prevent approving any projects that might be either too easy or too ambitious. With an overly ambitious project at least a less ambitious set of requirements can usually be "carved out" for the students. If a project does not have sufficient challenge it can be difficult to modify the requirements to raise it to a sufficiently high level. This is especially true if the project sponsors are asking for very little without regard for course requirements and goals. The natural tendency for many students is to gravitate to the level of least effort if they believe that is what they can get away with, or if that is what "should be required".

Course Assessment and Student Comments

A variety of assessment tools have been used to evaluate the effectiveness of the two-semester senior design project courses. These include exit interviews with graduating seniors. Some of these were video taped on "senior design day"; either during breaks or after the completion of the final presentations. Comments were also solicited from the industrial sponsors and faculty advisors. The majority of the comments were very positive with a few expressing concerns about what was perceived as inequities in the levels of challenge for some of the projects. This is the subject of ongoing discussions, with effort going into preventative measures to eliminate projects that are not at suitably high levels of challenge prior to advertising them to the students.

Because the senior design project sequence was new the course instructor organized a student advisory committee to provide feedback during and at the end of the semesters. The students were randomly selected so that a variety of student perspectives on the course could be obtained. Ten students met with the instructor twice each semester to discuss how things were going in the course and to provide the students with the opportunity to voice any concerns that they might have. The comments received were mostly positive, especially regarding how the course structure had forced the students to stay on task instead of falling into the pattern of "binge" work for long hours just before due dates. As expected some students complained about the very same thing, perhaps because they would rather have the freedom to put things off so they can concentrate more on other more traditionally organized courses. One student when asked for suggestions regarding possible changes to improve the course in the future replied that "you should keep everything the same in the first semester course."

One other area of concern expressed by a few students was that their industrially sponsored projects got off to slow starts because of a lack of regular and sufficient communications from the sponsors. They felt that they were at a disadvantage relative to other more completely defined projects. To address this concern some considerable flexibility was extended to those teams who were having difficulty obtaining the information needed to fully define their design problems. This flexibility involved requiring them to turn in preliminary versions of the first few mini-reports on-time, but with the ability to submit more complete reports as soon as possible. This worked well as long as the instructor stayed in direct communication with the affected teams and their advisors. The possibility of abuse is real, especially during the busier portions of the semester, such as near the middle of the term.

The second semester course is currently organized with considerably less structure than the first semester course. The only incentives for progress included are the weekly progress reports to advisors and industrial sponsors, and the midterm and final reports. In response to assessment results plans are being developed to require at two or three preliminary reports early in the term and one later in the term. These could include a design optimization/improvement report and a failure modes and effects (FMEA) report. The report to be required later in the semester is a plan for experimental work including data sheets to be used during testing. The instructor and/or project advisors will have to approve the reports, especially the experimental work plan, prior to the students being allowed to continue on their projects.

Conclusions and Recommendations

The two course senior design project sequence at Michigan Technological University has been organized to encourage timely completion of project related tasks. It also maintains a close connection in time between concept lectures and the reports that make use of those same concepts. This is especially true during the first semester course in which a "just-in-time" approach is being used to connect lecture topics to mini-report assignments. Judging from the quality of the results obtained to date, including professional quality written and oral reports, excellent posters and working prototypes the courses are effectively providing the mechanical engineering students with a good and valuable experience in engineering design

One of the problem areas in the course that needs further work is that of dealing more effectively with the different types of design projects. Part of this problem can be minimized by attention to details prior to offering projects to the students. By working with the industrial sponsors ahead of time many of the communications related startup problems can be eliminated. Also the difficulties associated with the different levels of challenge between projects can be remedied by having the course coordinator/instructor work more closely with the project advisors so that course requirements and expectations are thoroughly understood.

The overall response from students, faculty advisors and sponsors to the senior design project course sequence has been very positive. The course instructor, with the help of the faculty involved and the project coordinator is addressing those problem areas that have been identified. With time it is hoped that the course will get better at providing the students with a very positive experience in engineering design, one that they will look back at fondly with pride during long and productive careers as professional engineers.

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