Teaching Integrated Design and Manufacturing, Course Structure and Assessment

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Abstract

Until recently, most engineering and engineering technology programs taught coursework piecemeal – one subject at a time with little integration between subjects. The failure of this system is well documented and has led to outcomes assessment and the now familiar ABET a-k criterion. Faculty at Purdue University Calumet (PUC) recognized the shortcoming of the original system and applied for an NSF ILI-IP grant which was awarded in late 1997 and continued through mid 2000. The grant resulted in significant changes in the engineering course ME461, Machine Design and the creation of the technology course MET461, Computer Integrated Design & Manufacturing. With two years of experience available, this paper discusses the structure, pedagogy, and assessment techniques for the latter course, which concentrates on 3D parametric modeling, graphical finite element analysis, and manufacturing using ProE/ProMechanica/ProManufacture in its integrated environment. Some observations that faculty new in this area may find helpful complete the paper.

Background

Prior to the 2000 paradigm shift, ABET accreditation was referred to as a "recipe" (Neff & Scachitti, 2002). Unfortunately, the ingredients of the recipe were never mixed. Imagine placing eggs alongside flour, sugar, butter, and baking soda in a pan next to each other and expecting a cake to result. As educators, that was our response to the old ABET criteria. We simply created a course for each required topic and said the result was an engineer or technologist. Of course, that method did not work well, and many educators recognized that fact. At PUC, the mechanical engineering (ME) and mechanical engineering technology (MET) faculty prepared an NSF ILI-IP grant in 1996, which was funded the following year. The project, entitled Computer Integrated Design and Manufacturing Laboratory, August, 1997 to May, 2000, modernized the laboratory portion of five courses in the Mechanical Engineering and Mechanical Engineering Technology curricula. This project focused on concurrent engineering, which encompasses all phases of a product's life cycle from inception through design, prototyping, analysis, testing, manufacture, and recycling. Further information about this project is found at (Higley, Kin, Parsons, & Prochnow, 1999) and (Higley & Kin, 1999).

When completed in the spring of 2000, both ME461, Machine Design I and MET461, Computer Integrated Design & Manufacturing, had as their main core a set of experiments where students experienced design, analysis, rapid prototyping, manufacturing, and testing in small group projects. Initially, the following software was used:

Design: Mechanical Desktop from Autodesk
Analysis: DesignSpace from ANSYS
Manufacturing: Edgecam from Pathtrace Systems

The original experiments were tested in the ME courses ME461, Machine Design I and ME462, Machine Design 2 with good success in the late 1990's. Anecdotal student, alumni, and employer feedback suggested that the integration of topics in one course served to reinforce engineering concepts and helped the students tackle larger, more complicated projects sooner. Several students from these early classes went on to design and build impressive senior design projects. Perhaps the most popular of these was the putter head by Mike Vrska (Higley & Vrska, 2000) where his prototype golf putter landed him a prestigious position in the golf industry. Figure 1 shows the completed prototype that he designed, analyzed, rapid prototyped, and manufactured from exotic materials including investment cast titanium and machinable tungsten.

The only concern among students and faculty was the work required to maintain compatible versions of Mechanical Desktop, Designspace, and Edgecam. Whenever Autodesk released a new version of Mechanical Desktop, the other two would take up to several months to release compatible versions. The solution to that problem is to use an integrated software package.

MET 461, Computer Integrated Design & Manufacturing

Since the Mechanical Engineering Technology program did not have room in an existing course, a new course was added to teach integration topics, MET461. The course has the following objectives:

At the completion of the course, the student should be able to:

1. Explain the use and applications of parametric design
2. Explain the use and applications of finite element analysis (FEA)
3. Explain the use and applications of computer aided manufacturing (CAM) systems
4. Explain the integration of all aspects of a product's life cycle
5. Use parametric design, FEA, and CAM systems to design, analyze, and manufacture mechanical components

Figure 1

These objectives were designed to be measurable using standard assessment techniques. Indeed, the first four can be measured with simple short answer questions on tests, while the last one may be measured with laboratory projects and practical exams. Assessment issues will be covered in the following section, Pedagogical Issues.

Based on the course objectives, the following course description was approved:

> A combination of lecture and laboratory projects demonstrating the integration of all phases of a product's life cycle from inception through recycling. Laboratory projects include designing parts, graphical finite element analysis, rapid prototyping, computer controlled manufacturing, and testing using a common, three-dimensional database.

Pedagogical Issues

Course Structure

As a senior level course in a relatively small program, class sizes tend to be small as well, usually between 10 and 20. This small class size provides tremendous flexibility in course structure, but larger courses

Topics in MET461	
Topic	**Allotted Time**
Parametric modeling	8 weeks
Introduction to rapid prototyping	1 week
Introduction to finite element analysis	2 weeks
Introduction to CAM	2 weeks
Design Project	2 weeks

Table 1

should be adaptable with teaching assistants and reasonable lab sizes. MET461 is structured around a 15 week semester with the following main topics allotted time as shown in Table 1.

Texts

The faculty chose the ProEngineer/ProMechanica/ProManufacture suite of software for MET461 primarily because its integrated nature represents the central database for all functions quite well. In addition, textbooks are available. *Pro/Engineer Instructor* by David Kelley (2002) and *Pro/Mechanica Tutorial* by Roger Toogood (2001) are the current choices along with a Pro/Manufacture tutorial available on the web from David Kelley (2001). The Kelley (2002) book does a nice job of presenting many facets of parametric modeling, and the included examples give plenty of practice. The Toogood (2001) book has a nice introduction to FEA and good, practical examples. Only solid FEA models and optimization are covered in MET461 due to time limitations. The author is only aware of one text on Pro/Manufacture, but it lacks explanations. The Kelley (2001) tutorial does a much better job of covering the required topics, and it is available online.

Teaching Methods

While not explicitly stated as a course objective, the senior level students taking this course should be capable of learning on their own, and the instructor encourages that with his teaching methods. Each week, the instructor demonstrates the current topics while the students observe. The students are encouraged not to take detailed notes, but to observe the process and take rough notes on major characteristics. Then, the students carefully read the instructions in the texts and tutorials and perform the exercises themselves. The instructor then answers individual questions and occasionally interjects comments the whole class might find useful. As one might expect, some students work much more quickly than others and need little attention. The instructor is then free to assist the slower students. In the class sizes mentioned, this has proven to be an efficient teaching method as high grades on exams indicate. For the reasons stated above, this course has been well suited for the studio format of teaching.

Group Projects

In the parametric modeling, FEA, and CAM portions of the class, students turn in individual work. They tend to gravitate into small groups and ask each other questions, but they must turn in individual assignments. In the Rapid Prototyping and Project portion of the course, the students work in groups of three, and the entire group receives the same grade. The author does simple group self-assessment, which has been adequate so far. Considerable research on group self-assessment has been published in the literature, and these techniques will be implemented in the future (Kaufman, 2000).

In the first two sessions of MET461, the design project was a connective member similar to a chain link. The students were given the material, load, pin size and spacing, and tooling constraints, and then they designed and optimized a link. The team with the lightest link received a few bonus points. The groups each give a short design review at the end of the project. Figure 2 shows samples of student links. In the current session, the author hopes to integrate

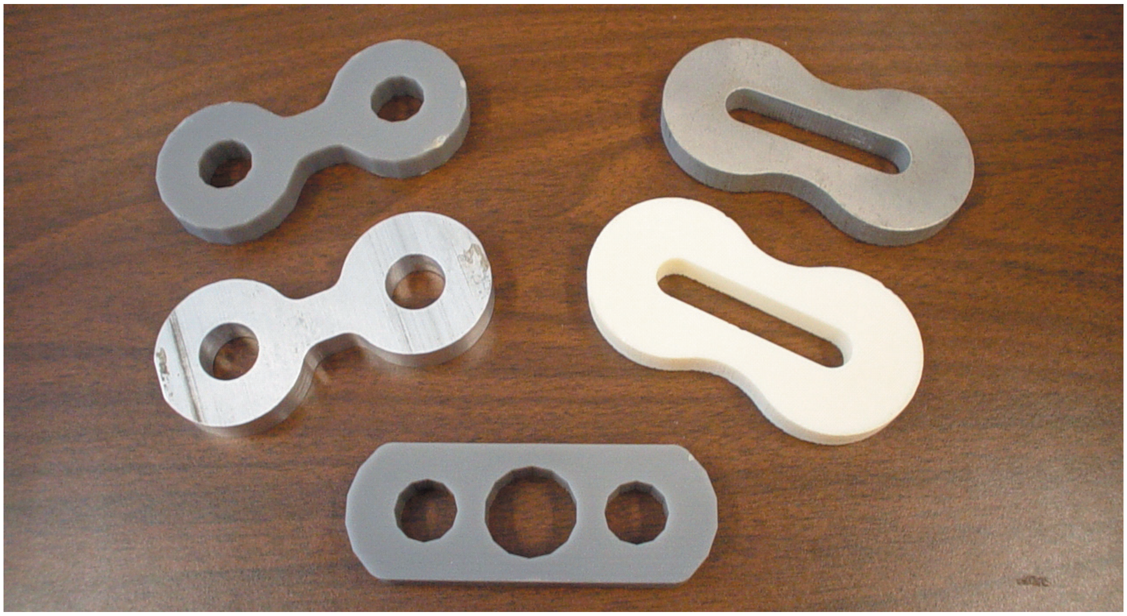

Figure 2

the link design into the standard FEA and CAM topics as exercises, and then have the students redesign a common tubing cutter as a design project.

Juricic & Barr at The University of Texas at Austin were early pioneers in implementing several technologies with their work dating back to at least 1990 (Juricic & Barr, 1996). With NSF Support, they have integrated the technical issues of concurrent engineering into the classroom using commercial software, simple rapid prototyping machines, and small, trainer CNC machine tools. Purdue University Calumet's connective link project follows closely that of Juricic & Barr (1996) but expands on the concept by using newer rapid prototyping technologies and full size CNC machine tools.

Course Assessment Techniques

A number of different assessment techniques are being used to determine the effectiveness of this course. Initially, the MET Program Industrial Advisory Committee was consulted during course development and initial objective design. In addition, an extensive on-line student assessment tool has been developed which will be offered in the near future. This tool is broken down into four parts: Student Self-assessment, General Course Impact (ABET concerns), Course Management, and Course Objectives. This tool has been designed with the first three sections common, and with the course objectives portion easily modified for different courses. The Student Self-Assessment Tool is shown in Table 2. This instrument it is based on the work of Land and Hager (2002). The course assessment tool is part of a larger project to perform integrated, on-line assessment of all courses in the METS Department. MET461 was the trial course used for the instrument. The students perform the assessment during regular course hours with a proctor in the room instead of the instructor. Blackboard is the delivery tool, and it tells the instructor when a student has taken the exam, but all responses remain confidential. Blackboard also summarizes the data and presents useful statistics.

Another assessment tool is a modified version of Land and Hager's (2002) instructor assessment tool. It is not designed to provide quantitative data, but merely to provide a place for the instructor to make comments on the course which might help

Student Assessment Tool

Specific Student Responsibility Questions:

1. I attended scheduled classes and labs.
   5. Always 4. Frequently/Often 3. Sometimes 2. Rarely 1. Never

2. I arrived on time for scheduled classes and labs.
   5. Always 4. Frequently/Often 3. Sometimes 2. Rarely 1. Never

3. I read the course material/text when it was assigned.
   5. Always 4. Frequently/Often 3. Sometimes 2. Rarely 1. Never

4. I was well prepared for class.
   5. Always 4. Frequently/Often 3. Sometimes 2. Rarely 1. Never

5. I participated in classroom discussions and activities.
   5. Always 4. Frequently/Often 3. Sometimes 2. Rarely 1. Never

6. I used the supplemental materials or website (Bb) my instructor provided.
   5. Always 4. Frequently/Often 3. Sometimes 2. Rarely 1. Never

7. My ability to apply knowledge from pre-requisite courses for this course can be rated as,
   5. Excellent 4. Good 3. Average 2. Poor 1. N/A - Not Applicable

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General Course Impact Questions:

8. As a result of this course, my mastery of the knowledge, techniques, skills, and modern tools of the Mechanical Engineering Technology discipline can be described as,
   5. Excellent 4. Good 3. Average 2. Poor 1. N/A - Not Applicable

9. As a result of this course, my ability to apply current knowledge and adapt to emerging applications of mathematics, science, engineering, and technology can be rated as,
   5. Excellent 4. Good 3. Average 2. Poor 1. N/A - Not Applicable

10. As a result of this course my ability to conduct, analyze, and interpret experiments and apply results to improve processes can be rated as,
   5. Excellent 4. Good 3. Average 2. Poor 1. N/A - Not Applicable

11. As a result of this course, my ability to apply creativity in the design of systems, components, or processes appropriate to program objectives can be rated as,
   5. Excellent 4. Good 3. Average 2. Poor 1. N/A - Not Applicable

12. As a result of this course, my ability to function effectively on teams can be rated as,
   5. Excellent 4. Good 3. Average 2. Poor 1. N/A - Not Applicable

13. As a result of this course, my ability to identify, analyze, and solve technical problems can be rated as,
   5. Excellent 4. Good 3. Average 2. Poor 1. N/A - Not Applicable

14. As a result of this course, my ability to communicate effectively can be rated as,
   5. Excellent 4. Good 3. Average 2. Poor 1. N/A - Not Applicable

15. As a result of this course, my recognition of the need for, and an ability to engage in lifelong learning can be rated as,
   5. Excellent 4. Good 3. Average 2. Poor 1. N/A - Not Applicable

16. As a result of this course, my ability to understand professional, ethical, and social responsibilities can be rated as,
   5. Excellent 4. Good 3. Average 2. Poor 1. N/A - Not Applicable

Table 2

Table 2 (continued)

17. As a result of this course, my respect for diversity and knowledge of contemporary professional, societal, and global issues can be rated as,
5. Excellent 4. Good 3. Average 2. Poor 1. N/A - Not Applicable

18. As a result of this course, my commitment to quality, timeliness and continuous improvement can be rated as,
5. Excellent 4. Good 3. Average 2. Poor 1. N/A - Not Applicable

Specific Course Management Questions:

19. My instructor passed out a syllabus or made one available in the Internet early in the course.
5. Strongly Agree 4. Agree 3. Neither Agree or Disagree 2. Disagree 1. Strongly Disagree

20. I was able to understand the syllabus and grading procedures.
5. Strongly Agree 4. Agree 3. Neither Agree or Disagree 2. Disagree 1. Strongly Disagree

21. The instructor followed the syllabus.
5. Strongly Agree 4. Agree 3. Neither Agree or Disagree 2. Disagree 1. Strongly Disagree

22. Given the ease or difficulty of the material presented in this course, the exams represented the topics covered fairly.
5. Strongly Agree 4. Agree 3. Neither Agree or Disagree 2. Disagree 1. Strongly Disagree

23. The course assignments were related to the material being covered.
5. Strongly Agree 4. Agree 3. Neither Agree or Disagree 2. Disagree 1. Strongly Disagree

24. The laboratory assignments in this course help reinforce the topics being covered and make them easier to learn. (Only for classes with labs.)
5. Strongly Agree 4. Agree 3. Neither Agree or Disagree 2. Disagree 1. Strongly Disagree

25. My instructor returned graded material such as homework and tests in a timely manner.
5. Strongly Agree 4. Agree 3. Neither Agree or Disagree 2. Disagree 1. Strongly Disagree

26. My instructor was on time and prepared for class.
5. Strongly Agree 4. Agree 3. Neither Agree or Disagree 2. Disagree 1. Strongly Disagree

Specific Course Objective Questions:

27. A specific objective of this course is to explain the use and applications of parametric design. How well did this course meet this objective?
5. Excellent 4. Good 3. Average 2. Poor 1. N/A - Not Applicable

28. A specific objective of this course is to explain the use and applications of finite element analysis (FEA). How well did this course meet this objective?
5. Excellent 4. Good 3. Average 2. Poor 1. N/A - Not Applicable

29. A specific objective of this course is to explain the use and applications of computer aided manufacturing (CAM) systems. How well did this course meet this objective?
5. Excellent 4. Good 3. Average 2. Poor 1. N/A - Not Applicable

30. A specific objective of this course is to explain the integration of all aspects of a product's life cycle. How well did this course meet this objective?
5. Excellent 4. Good 3. Average 2. Poor 1. N/A - Not Applicable

31. A specific objective of this course is to use parametric design, FEA, and CAM systems to design, analyze, and manufacture mechanical components. How well did this course meet this objective?
5. Excellent 4. Good 3. Average 2. Poor 1. N/A - Not Applicable

Course Assessment Tool

MET461 Computer Integrated Design & Manufacturing Course Assessment Tool Semester: Instructor:						
ABET Criterion Satisifed: a,b,c,d,e,f,h			MET Program Strategic Plan Supported Objective(s): 1, 2, 4			
Course Objective	**Assessment Tool 1**	**Score**	**Assessment Tool 2**	**Score**	**Assessment Tool 3**	**Score**
Explain the use and applications of parametric design.	Final Exam					
Explain the use and applications of finite element analysis (FEA).	Lab Assignments		Final Exam			
Explain the use and applications of computer aided manufacturing (CAM) systems.	Lab Assignments		Team Project			
Explain the integration of all aspects of a product's life cycle.	Team Project		Final Exam			
Use parametric design, FEA, and CAM systems to design, analyze, and manufacture mechanical components.	Lab Assignments		Midterm and Final Exams		Team Project	

Table 3

interpret the data generated from the student assessment tool.

The final course assessment tool relates student grades against the course objectives as shown in Table 3. Much research on course assessment tools of this type is available (Henderson, Jeruzal, & Pourovahed, 2002), and this is among the simpler types. The author intentionally created a simple instrument because these forms must be generated for 23 courses at the same time, and the faculty felt a short, simple instrument would be the best place to start. After results have been analyzed from a year or two's data, the forms will be revisited.

Conclusions

Ideally, students would know parametric modeling before entering MET461, and the whole course could concentrate on the other issues such as FEA, CAM, and student projects. This is not possible at Purdue University Calumet because local industry demands AutoCAD in the early CAD courses and because our non-traditional students may have several years between the early CAD courses and MET461.

For a newcomer, the licensing and installation of the ProE Suite can be daunting, but possible with technical support. Students can also purchase individual copies of the ProE suite from www.journeyed.com and many will do so to afford themselves the comfort of working at home.

Finite element analysis is an area that seems easier than it is, especially with graphical tools. As an example for students, have them draw a one inch square bar of aluminum 12 inches long, constrain one end, and apply a 10,000 pound load on the other. Everyone will expect a uniform stress of 10,000 PSI. However, with no consideration

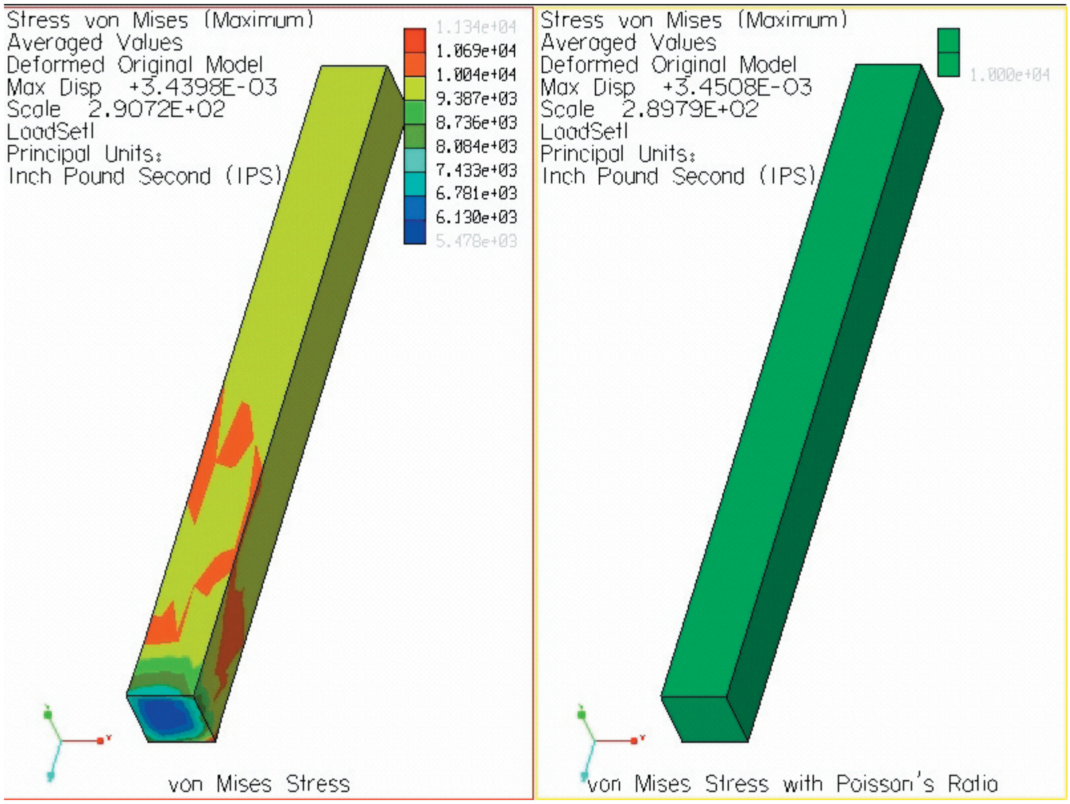

Figure 3

for Poisson's ratio on the constrained end, stress will vary widely. Another model which accounts for Poisson's ratio shows uniform stress distribution. Figure 3 illustrates the difference with and without Poisson's ratio.

Most FEA books are designed for senior or graduate level engineering courses, and they are much too in-depth for an overview course. On the other hand, instruction books such as Dr. Toogood's (2001) cover very little theory and concentrate on the software. There is one book that the author is aware of, *Building Better Products with FEA*, by Vince Adams and Abraham Askenazi (1999) that bridges the gap. This excellent book describes the power and pitfalls of FEA that a reasonably competent technical person can understand. It is the author's first recommendation when a person would like to learn FEA.

The content of MET461 is evolving. As 3D modeling gets easier and is moved into lower level courses, more time will be spent on analysis, testing, and manufacturing. Assessment techniques are evolving as well. PUC's METS Department will continue to assess and validate these assessment tools.

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