

Integrating Manufacturing, Design and Teamwork into a Materials and Process Selection Course

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Introduction

During the 2000 – 2001 academic year, the Manufacturing Engineering program at Kettering University underwent a significant curriculum reform in preparation for ABET accreditation. Traditionally, the program offered an introductory manufacturing processes course at the freshmen level followed by an introductory engineering materials course at the sophomore/junior level. These courses were the primary prerequisites prior to the advanced manufacturing processes courses.

During the curriculum reform discussion it was decided that an intermediate course was needed to better integrate these introductory courses with the advanced manufacturing processes courses. In addition, the course would reinforce those skills identified in the ABET criteria that are not often encountered in a traditional engineering course (e.g. design, teamwork, communication skills, contemporary issues, social impact of engineering, etc.), and that were missing from the program according to preliminary assessment results.

The resulting course, MFGG 375 Materials and Process Selection, was developed with assistance from the National Science Foundation. The course was offered for the first time during the Winter 2002 term (January – March). A second offering occurred during the Spring 2002 term (April – June). The course includes three hours of weekly discussion periods and two hours of laboratory time. The following provides an overview of the course design, teaching methodology, laboratories and projects, as well as, course and project evaluation plans.

Project Description and Objectives

The goal of the project is to develop, implement and evaluate a team-based course focused on material and process selection methods, but which also focuses on other topics relevant to practicing manufacturing and mechanical engineers. These additional topics include life cycle engineering as it applies to materials, the role of materials selection in the design process, economic decision making for manufacturing processes and understanding risk and liability for materials selection. In addition the course emphasizes teamwork and communication skills through a series of team-based projects requiring written and/or oral reports. The specific project objectives are identified in the table below.

**Table 1: Project Objectives for NSF CCLI Grant to Develop a
Materials and Process Selection Course**

Objective	Description
1	Provide tools that enable students to select, and research, the appropriate material and processing methods for manufacturing a particular product
2	Integrate product design and development concepts with manufacturing engineering topics
3	Address identified shortcomings in specific ABET criteria focused on teamwork, communication, the social impact of engineering, etc.
4	Increase the laboratory throughput and capabilities to use lab time more efficiently for problem-based inquiry
5	Increase the reported satisfaction of the students' co-op employers
6	Dissemination of findings

Early in the project an oversight committee was formed to provide assistance with course development efforts and serve as an impartial source of evaluation. The committee consists of both internal (Kettering University) and external evaluators. Internal evaluators include faculty from Manufacturing Engineering, Communications and Business. External evaluators include three technical evaluators and an evaluation consultant. The technical evaluators include faculty from California Polytechnic State University and Virginia Polytechnic Institute & State University that teach courses in materials selection, and a practicing engineer responsible for green design initiatives at General Motors.

The oversight committee met in early October 2001 to discuss the philosophy of the course and the course content. Early indications are that the committee is pleased with the course's direction and are very supportive of the efforts being made.

Course Content

The course content is divided into six modules, described here in chronological order.

Module 1: Unified Life Cycle Engineering

A common complaint of engineering undergraduates is that they lack the breadth to see the impact of engineering and design on a company's business and society in general. The course addresses this competency gap by first showing students how design fits into the overall life cycle of a technology, product and process, and how these three cycles are in turn involved in a single unified life cycle for product development, design and production. This view helps students identify the impact their decisions will have on the business and society both upstream and downstream of the engineering function. For example, a designer may call for a composite door panel to meet the design objective of a light-weight automobile to improve fuel efficiency. However, without a full life cycle view, the engineer may not realize the difficulty in recycling composite materials. While this has a direct effect on society (e.g. increased solid waste and resource usage), it may also cost the company in the long run if 'take-back' laws similar to those in the European Union are implemented for manufacturers in the United States.

Module 2: The Design Process

Students begin by discussing the difference between a technical system approach to design and a functional system approach. To provide an analogy, according to a technical system approach a frog would consist of legs, skin, and organs, while a functional system approach would include the musculoskeletal system, cardiovascular system, nervous system, etc. The functional system approach focuses on how a 'product' operates rather than how it is assembled. This is a concept that students often struggle with, but is essential to conducting proper material selection.

Students also study the design process with an emphasis on the conceptual design stage. In particular students discuss customer needs identification, problem definition, benchmarking, gathering information, generating design ideas and drafting a design specification. Students also spend some time discussing the importance of codes and standards for design.

Finally, students are exposed to the idea of design for the environment (DfE) through a 1 hour workshop conducted by the oversight committee member from General Motors (GM). During the workshop, students discuss what DfE is and why it is becoming an increasingly important engineering function in leading corporations. Following this, students are led through a group activity involving a facilitated discussion of an actual "green design" initiative, where they are divided into teams representing separate factions within the corporation to argue the merits of the initiative from different points of view. After the group activity the visiting expert reveals how GM implemented this particular initiative.

Module 3: Materials Selection

The module begins with an explanation of the possible consequences of improper materials selection and why it is important to conduct materials selection in the earliest stages of design. Students are then introduced to selection criteria that may be used in a selection and to various methods for materials selection including computer databases, selection matrices (Pugh and weighted property index methods), and materials performance indices. Emphasis is placed on materials performance indices and their use in the Ashby method of materials selection¹. This is essential since the Ashby method is used in the material and process selection software purchased for the course, the Cambridge Engineering Selector (CES)². The Ashby method develops a material performance index based on the function and objectives of a design. For example, the material performance index (M) of a light-weight, stiff beam would be $M=E/\rho$, known as the specific modulus. On a plot of elastic modulus (E) and density (ρ), we can set up a guideline with slope of 1 (see Figure 1), such that all materials along that line have an equal value of M, and therefore, equally satisfy the design requirements. This allows students to quickly determine the materials that would meet the design requirements, when used in combination with other property limits.

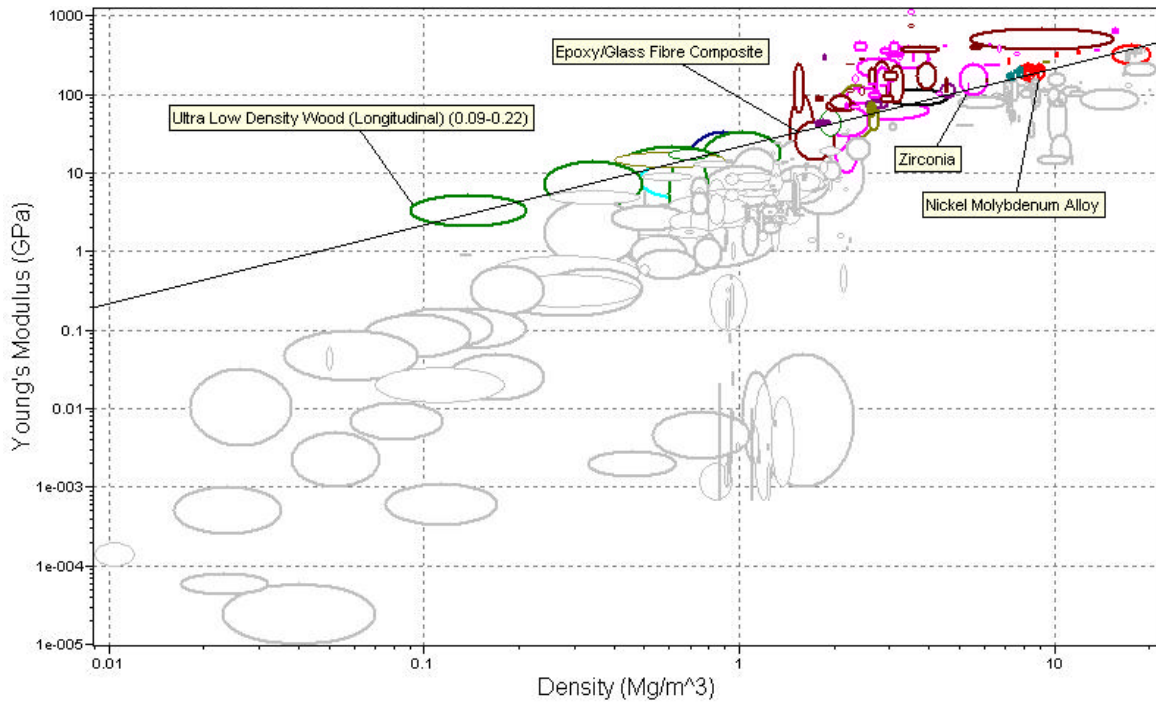


Figure 1: Ashby plot of elastic modulus versus density with guideline of slope 1 for maximizing the selection of a material for a light, stiff beam.

Module 4: Process Selection

In this next module it is assumed that students have mastered the concepts surrounding materials selection and now wish to determine how to make a product from the material they have selected. This section of the course focuses primarily on using the Ashby method to select a process based on all process attributes, such as the materials it can handle, shapes and sizes it can produce, tolerance, roughness, economic batch size, etc. The initial step is to conduct a screening to reduce viable processes from all those known to 3-4 options that meet the necessary product requirements. This is accomplished using the same computer database described above (CES). The next step is to examine the economics of the process to rank the remaining candidates by anticipated cost. This involves economic modeling that is introduced to students in the simplest terms possible.

Module 5: Economic Decision Making

The purpose of this module is to provide students with basic engineering economics to help them understand the implications of design and manufacturing decisions on a company's bottom line. This involves presenting students with elementary cash flow models, net present value concepts and a simple approach to return on investment. Students also discuss various cost designations associated with manufacturing processes including variable costs, capital costs, labor, facilities, management and overhead.

Module 6: Risk, Liability and Safety

Students begin this module by discussing a definition of risk, how it might be assessed and when it is acceptable. These concepts are introduced in terms of practical engineering applications where possible. Students then discuss the idea of design for reliability, focusing on what factors may make a product unreliable and how to minimize this unreliability, particularly as it relates to

materials. Students are also introduced to the method of Failure Modes and Effects Analysis as a means of minimizing unreliability in design and ensuring safety at the earliest design stages. Finally, lest students fail to understand why safety is important there is a brief discussion of product liability and the engineer's responsibility to society to produce a reasonably safe product.

Educational Philosophy and Methodology

The teaching method used in MFGG 375 is based on three pedagogical concepts: Kolb's learning cycle, active learning and cooperative learning. Kolb's learning cycle^{3,4} is generally presented as a two dimensional circular model of how people learn as shown in Figure 2. This model places learners along two distinct dichotomies. The first divides learners between those who prefer active experimentation (AE) and those who prefer reflective observation (RO), and examines how individuals convert experience into knowledge. The second dichotomy deals with how individuals comprehend knowledge. In this dichotomy individuals are divided between those who want concrete experience (CE) and those who prefer abstract conceptualization (AC). These two dichotomies are orthogonal, creating four separate quadrants. An individual's learning preference is described by the quadrant they would be most comfortable with. Starting with the upper right hand quadrant and working clockwise, these quadrants represent individuals who learn best through: 1) motivation (why?), 2) conceptualization (what?), 3) practice (how?) and 4) experimentation (what if?).

In MFGG 375, the approach is to direct the class through all four quadrants of Kolb's learning cycle to challenge all students. Students are first given motivation for studying a new topic through applications (why?). Next, students learn the principles involved through their own reading, lecture, and discussions (what?). Students then practice this knowledge through in-class active learning strategies and out-of-class projects (how?). Finally students are given the opportunity to experiment with their new knowledge in the laboratory and through the open-ended projects (what if?).

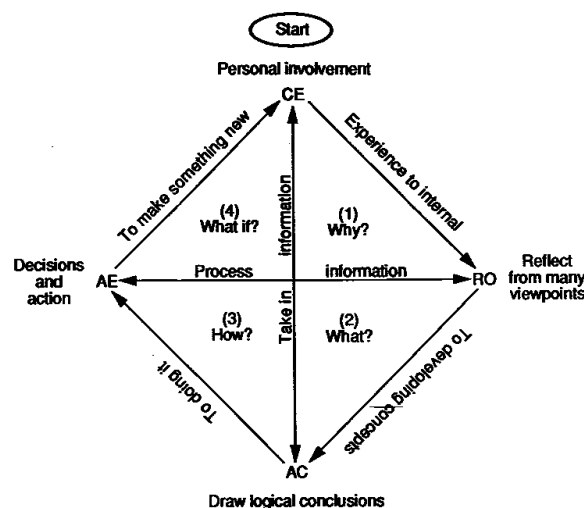


Figure 2: Kolb's Learning Cycle (from Wankat and Oreovicz⁵)

The other two pedagogical approaches used in the class are cooperative learning and active learning. In reality, these two methods are very closely related in that the former is often

considered a subset of the latter. Active learning is a method based on the idea of getting the students actively involved in their own learning. Cooperative learning is essentially teamwork that can range from 5 minute in-class activities to semester-long formal design projects. In MFGG 375, the instructor has incorporated a wide variety of active learning techniques into the lecture notes for the course during which students work in informal cooperative learning groups. In addition, students are formed into formal cooperative learning groups for completion of the term projects.

Laboratory Experiences

The laboratory experience is divided into three distinct lab assignments. During the term there are 9 lab periods, so that each lab assignment requires approximately 6 hours to complete (3 lab periods of 2 hours each). For the second and third labs, students are to work together as a class to complete the laboratory and then work within their cooperative learning groups to write up the laboratory report. It should be noted that at the time of this paper, equipment needed for the last two labs was not yet functional so that these labs have not yet been run. The key element of the report is a requirement that students must make a logical choice between multiple alternatives based on collected data and thoughtful analysis.

The first lab focuses on training students to use the Cambridge Engineering Selector (CES) software for later use in materials and process selection projects. The lab is held in a computer facility where students work through a series of tutorials on the basic functions of CES. They are given frequent opportunities to test their skills and explore the software's functions, and each lab period ends with a short take-home assignment using CES.

The second lab will examine the effect of sintering conditions on the mechanical properties of injection molded metallic powders. Students will create tensile bars from three different metal powders using injection molding equipment available in Kettering University's polymer processing lab. These bars will then be sintered in an atmosphere-controlled furnace for various periods of time. Students will determine the strength and ductility of each sample, followed by metallographic preparation and examination to determine the extent of porosity of each sample. As an assignment, students will be asked to find the same metals in the CES software and compare their measured properties with those provided in the database. The goal is to help students understand that care must be taken when using a database to select materials because these tools may not always take processing conditions into account.

The third lab will introduce students to two competing processes for carburizing steel, a common practice in the automotive and heavy machinery industries of the Midwest. Students will examine both a gas and a pack carburization process. Using an optical metallurgical microscope and microhardness tester, students will measure the extent of case depth and surface hardness variation. They then use this data to produce models of the carburization process using simple diffusion equations learned in a previous course. The models are used to predict which process is more economically feasible given data for a simulated production environment. The goal is to help students connect material testing and analysis with simplified computational models and economic predictions to select between two very similar processes.

Projects

During the term, students work in their learning teams to complete several projects. Each project focuses on one or more of the modules described above. The projects are intended to assess not only whether they understand the technical content of the modules, but also their ability to communicate effectively. Each of the projects requires some additional research for successful completion.

The first project focuses on the role of engineering and design in the life cycle of materials. Learning teams are asked to write a brief report based on their literature search and collective discussion. As an example, students in one term were asked to describe how the concept of green design and industrial ecology differ from past approaches to engineering design, and provide examples of how green design concepts have altered common products.

The second project addresses materials selection for a particular design project. Products are chosen that intentionally have simple geometries and loading conditions to make the materials selection process more reasonable for the students. Example products include golf club shafts, bike frames, dock pilings, inexpensive housing materials and power transmission poles.

For the third project students must select an appropriate and economical process for manufacturing some product. Typical products include plumbing fixtures, golf club heads, and automotive components such as valves, steering knuckles, control arms and engine blocks.

In the final project, students combine concepts learned in the previous three projects (life cycle engineering, design process, material selection and process selection) with economic considerations they have recently learned to develop a business plan for developing a product with an emphasis on proper materials and process selection. This project culminates in a final written report and an oral presentation at the end of the term.

Assessment and Evaluation Plans

Assessment and evaluation of the project is broken into two semi-autonomous classifications: assessment of course learning objectives and evaluation of project objectives. At the time this paper was written no assessment or evaluation data was available; however, some preliminary data will be presented at the conference.

Assessing the effectiveness of the course in achieving the learning objectives is an important component of overall project evaluation. Course and student level assessment is the responsibility of the course instructor and other manufacturing engineering faculty where assessment procedures overlap those already in place for program assessment.

Project evaluation is equally important during the grant period and is the responsibility of the oversight committee working in conjunction with the course instructor. Project evaluation focuses on determining whether the project objectives described above have been met. Several tools have been developed for evaluating the objectives. For example, an on-line survey will be created to address objective 1 (providing tools for materials selection) and 4 (increasing laboratory throughput). Students who had previously taken courses in the metallurgy laboratory

will be asked to complete the survey to generate a base-line for comparison with responses from students in MFGG 375.

To address objective 2 (integrating product design with manufacturing concepts), two approaches will be taken. The first will be to have the oversight committee review the course syllabus, lecture materials and projects to determine whether design and manufacturing are being properly integrated. Second, approximately mid-way through the term, an outside educational evaluator from the Kettering University Center for Excellence in Teaching and Learning will visit the classroom to conduct a Small Group Instructional Diagnosis (SGID), that will seek more in-depth assessment of the program objectives.

Objective 3 (addressing teamwork, communication, social impact of engineering, etc.) will be difficult to assess. Several tools will be used to help the instructor and evaluator determine the impact of the course on these important competencies. For example, assessment of teamwork skills will involve three separate evaluations: instructor, peer and self evaluation. Instructor level assessment will involve observation of both the formal and informal cooperative learning groups during in-class exercises. The data from these observations can be tracked during the term to identify whether an improvement has been made. Peer evaluation will be accomplished through a form that students will fill out at the mid-term mark and at the end of the term. Self evaluation will be more qualitative as students are asked to reflect on their performance as a team member by writing in their academic journals. Tracking improvements in writing quality in journals, lab reports and projects will similarly assess communication skills.

Finally, objective 5 (improving satisfaction of co-op employers) will be assessed through both interviews with actual co-op employers and results from Kettering University's "Supervisor's Evaluation of Student's Co-Op Experience" survey. In addition to questions focused on the benefit of the course content to a student's co-op performance, we can inquire about any improvement in their teamwork skills, communication skills and understanding of the impact of engineering on society, which may further assist in our assessment of objective 3.

Conclusions/Summary

The objective of the project described here is the development of a course that provides better integration of materials and advanced processing courses in the Kettering University Manufacturing Engineering program, while at the same time providing coverage of particular ABET program outcomes that have been overlooked in the past. In particular the course focuses on selection of materials for mechanical design and subsequent selection of the process to manufacture this product. Additionally, the course offers content on the impact of materials selection and manufacturing on the environment, introductory economics and development of communication and teamwork skills.

Primary responsibility for the course rests with the authors of this paper. However, an oversight committee including faculty from other universities, industrial advisors and evaluation experts provides guidance. The course is based on lectures, out-of-class projects and laboratory experiences for the students. The lectures are organized around the educational philosophy of Kolb and incorporate active learning and cooperative learning where possible. Assessment of the project includes surveys of students and future co-op employers, teamwork and

communication skills evaluation, and oversight committee review. Finally, the authors would like to acknowledge the generous support of the National Science Foundation.

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References

- 1 Ashby, M.F., *Materials Selection in Mechanical Design*, 2nd Ed., Butterworth-Heinemann, Oxford, UK, 1999.
- 2 CES is produced by Granta Design Ltd., <http://www.granta.co.uk>
- 3 Kolb, D.A., *Experiential Learning: Experience as the source of learning and development*, Prentice-Hall, Englewood-Cliffs, NJ, 1984.
- 4 Kolb, D.A., *Learning Style Inventory*, McBer & Co., Boston, 1985.
- 5 Wankat, P.C. and Oreovicz, F.S., *Teaching Engineering*, McGraw-Hill, New York, 1993.

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