AC 2009-27: A TOP-DOWN APPROACH FOR TEACHING AN INTRODUCTORY ENGINEERING MATERIALS COURSE

Priya Manohar, Robert Morris University

Dr. Priyadarshan Manohar is an Assistant Professor of Manufacturing Engineering at Robert Morris University, Pittsburgh, PA. He has a Ph. D. in Materials Engineering (1998) and Graduate Diploma in Computer Science (1999) from University of Wollongong, Australia and holds Bachelor of Engineering (Metallurgical Engineering) degree from Pune University, India (1985). He has worked as a post-doctoral fellow at Carnegie Mellon University, Pittsburgh (2001 – 2003) and BHP Institute for Steel Processing and Products, Australia (1998 – 2001). Dr. Manohar held the position of Chief Materials Scientist at Modern Industries, Pittsburgh (2003 – 2004) and Assistant Manager (Metallurgy Group), Engineering Research Center, Telco, India (1985 – 1993). He has published 45 papers in peer-reviewed journals and conferences including a 2007 Best Paper Award by the Manufacturing Division of American Society for Engineering Education (ASEE), three review papers and three book chapters. He has participated in numerous national and international conferences. He is a member of ASM International, TMS, ACerS, ISNT, ASEE and a registered Chartered Professional Engineer. Dr. Manohar's research interests include mathematical and computer modeling of materials behavior, thermomechanical processing of steels and other metallic materials, microstructure characterization and structure – property relationships. He has conducted a number of technical failure investigations, consulted on various materials-related problems, and acted as an expert witness in the Court of Law.

A Top-Down Approach for Teaching an Introductory Engineering Materials Course

1. Background

It is recognized that teaching an introductory engineering materials course to non-major students is a complex task due a variety of reasons [1 – 4] such as the interdisciplinary nature of the subject matter, non-linearity of structure - property interactions, and the ever-expanding array of modern materials and manufacturing processes. In a previous paper [4], the author outlined the utilization of a two-tier teaching plan to effectively deal with these challenges. In the first tier, called as ‘essential teaching plan’ all of the essential teaching elements were included (class notes, assignments, exams, lab experiments and so on). The second tier, termed the ‘course enrichment plan’, a range of innovative ideas were described that are in-tune with the contemporary teaching – learning environment such as multi-media resources. However, it was realized at that time that perhaps more efforts were still required to meet students’ needs and interests to get them motivated to learn about materials and incorporate that information creatively into their design of products and processes. In this regard, yet another approach was attempted where a new teaching scheme based on a ***top-down*** approach was developed and implemented during the Fall 2008 term.

The big idea behind this approach is to expose the students to the wider world of materials and their properties and applications without asking them “how” or “why” questions during the first four weeks of the 15-week term. The teaching approach started by analyzing designs of existing products and components to deduce property requirements, the focus then moved on the selection of materials, then to the choice of manufacturing processes, and finally to the insight as to why these materials are able to do the job that is required of them – this enquiry being the essential building block of materials science knowledge. The remainder of the term was the supplementary ***bottom-up*** approach that followed the conventional body of knowledge sequence such as crystal structures, phase diagrams, heat treatment principles and so on. The top-down approach included among other things two main teaching tools. The first tool consisted of ***literature research*** projects conducted by each student on a contemporary topic in materials engineering. The students were given research papers from current materials science journals as their primary resource. The students were also asked to support their research through additional library-based or internet-based research as appropriate. They collected, read and analyzed the relevant information and presented it back to the class. The second tool was the utilization of an industrial-grade materials engineering software package [5] to solve several ***materials design challenges***. The students selected, analyzed and optimized the choice of appropriate materials for a given application not only from mechanical property point of view, but also from manufacturing economy, environmental impact, sustainability, aesthetics, and energy efficiency points of views [6 - 9]. The effectiveness of this approach is presented here in terms of student feedback, student performance in the course, and ABET outcomes assessment.

2. EduPack Design Projects

EduPack design projects were compiled from various resources [10, 11]. The projects were graded according to the degree of difficulty and complexity of analysis involved. Some examples of the projects are provided below:

- Find the records first for the composite **CFRP (Carbon-fiber reinforced polymer).** It is in the family HYBRID, under Composite. Which has the higher tensile strength? Which has the lower density? What is CFRP used for? Is it denser or less dense than Magnesium? Can CFRP be shaped by water-jet cutting?
- Search on **cutting tool** to find materials that are used to make industrial cutting tools. You will find that some are metals, but many others are ceramics – why, in your opinion, ceramics make good cutting materials?
- The property **Fracture toughness** is a measure of how well a material resists fracture. A brittle material like glass has a low value of fracture toughness – around 1 in the units you will use ($MPa.m^{1/2}$) while steel used for armor has a very high value – over 100, in the same units. Many engineers, when designing with metals, avoid material with toughness less than 15. Use a Limit stage to find materials with fracture toughness greater than 15 and that are also **Good electrical insulators.**
- You want to make a casing for a mobile phone, exotic in color and design. It snaps onto the front of the phone, transforming it from a drab object to one of glamour. Research reveals that the shape is best made by **Thermoforming** (a very cheap process for shaping polymer sheet into dished and curved shapes) and that the decoration is best applied by **In-mold decoration** that can be done at the same time as the thermoforming. Find materials that can be processed in this way.
- Select material for the lens of an automobile headlamp: Headlamp lens protects the bulb and reflector and focuses the light where it is most needed. The project is to use CES to select materials for the lens. Develop material property requirements such as:
  - ✓ Must be **transparent** with **optical quality**.
  - ✓ Must be able to be **molded** easily.
  - ✓ Must have very good **resistance to fresh and salt water**
  - ✓ Must have very good **resistance to UV light**
  - ✓ Good abrasion resistance, meaning a high **hardness**
  - ✓ Low **cost** Price (USD/kg)
- Select material for Disposable Cutlery: If you eat at an expensive restaurant, the knives may have steel blades and ivory handles, and the forks and spoons could be made of silver. But if you eat at a local fast food joint or on an airplane, the same function is fulfilled by disposable plastic cutlery. The function is unchanged; but the objectives, clearly, are different: minimizing cost and – you might hope – maximizing recyclability or renewability (sustainability). Satisfying the property needs for the required function imposes constraints on material and shape: the plastic fork that snaps in half the first time you use it is only too familiar. Minimizing cost makes choice of process critical, and the material itself must also be cheap. Develop material property requirements such as:
  - ➢ Young's Modulus > 1.7 GPa
  - ➢ Tensile Strength > 24 MPa

- Cost < $1.8/kg
- Manufacturing process: economical for batch sizes >= 100,000 pieces
- Recyclable
- Bio-safe
- Corrosion resistant
- …

Exercises like these allows the students a high level exposure to different materials, their practical applications, properties of materials that fulfill not only the conventional technical design criteria, but also more advanced design criteria including cost, processing, endurability (resistance to overload, fatigue, corrosion, impact, and temperature), recyclability, biocompatibility, sustainability, energy efficiency and environmental impact. Students seemed to enjoy researching different alternative materials and discussing them with each other to find the best choice for a set of design criteria or given application.

3. Materials Research Projects

Students were given a list of contemporary materials research topics and asked to choose a topic for study over the next eight-week period. They were provided with a journal that contained at least one research paper related to the topic they chose. The journals are published various professional materials societies including the following:

- The Minerals, Metals, and Materials Society (TMS): *Journal of Materials (JOM)*
- ASM International (ASM): *Advanced Materials and Processes (AMP)*
- Association for Iron and Steel Technology (AIST): *Iron and Steel Technology*

The students were expected to study the specified research paper in the referenced paper and also collect any other information they may consider relevant. They were expected to make an oral presentation at the end of eight-week period summarizing the content of that paper in such a manner that the rest of the class gets an idea of the kind of material they researched. This task was worth 20% towards their course grade. Some examples of materials research projects are given in Table 1.

Table 1. Examples of Materials Research Topics.

Research Topic	Reference Journal
Nuclear Materials and Safety	JOM, April 2007 and Jan. 2008
Continuous Casting of Steel	Iron & Steel tech., July 2008
Safety Issues in Steel Mills	Iron & Steel Tech., April 2008
Titanium and its Alloys	JOM, Sept. 2006
Nanomaterials for Electronics	JOM, Dec. 2005 and Mar. 2007
Composites for Aircrafts	AMP, Mar. 2007 and June 2007
Mathematical Modeling in Material Design	JOM, Sept. 2007
Introduction to Biomaterials	JOM, July 2006
Lead-free Solders	JOM, July 2007 and June 2008
High Temp Materials and Super Alloys	JOM, Jan. 2006 and July 2008
Aluminum and its Alloys	JOM, May 2006 and Aug. 2007
Sharp Biomaterials	JOM, March 2008
Hydrogen Economy and Fuel Cells	JOM, Aug. 2006 and Dec. 2007
CO_2 Reduction Technologies	JOM, Feb. 2008
Overview of Steel Industry	Iron and Steel Tech., Sept. 2007
Automotive Materials	AMP, April 2007

4. Effectiveness of the Top-Down Teaching Approach

The new approach was implemented during the Fall '08 term and the achieved results were compared with those of the previous terms. The teaching effectiveness was assessed using three different tools as follows:

- Student performance in the course
- ABET Course Outcomes Assessment, and
- Student Feedback Survey

The results obtained are presented in the following sections.

4.1 Student Performance

The student performance in the current and previous terms is shown in Figure 1.

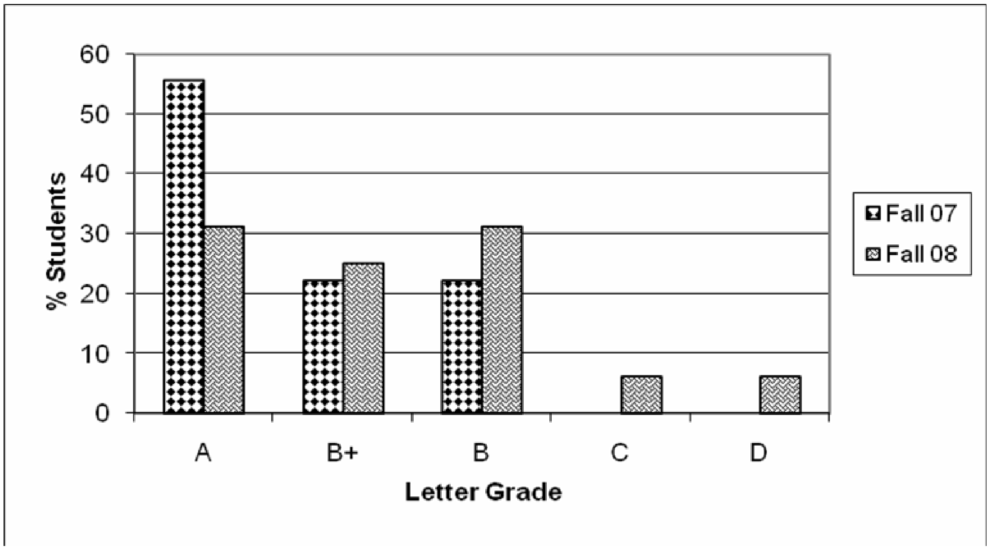

Figure 1: Student final grade distribution for the current and previous terms.

It is evident from Figure 1 that the students performed well during the current year. This performance is more evenly-distributed than the previous fall term across the letter grades. The data suggests that it was harder for the students to obtain A grades in the top-down approach as compared to the conventional approach.

4.2 ABET Outcomes Assessment

The course description is given as follows:
Engineering Materials (Sophomore Year Fall Term): The course content includes an examination of engineering materials such as metals, plastics, ceramics, and composites with an emphasis on material selection. Processing for the optimization of material properties is covered extensively, as is material cost estimation for manufacturing. Applicable ABET Outcomes are: 1, 2, 4, 5, 7, and 11. Applicable Track-Specific ABET Outcomes are: M1 and M5. The definitions of the applicable ABET outcomes are given for quick reference at the end of this section.

ABET Outcomes are: Engineering graduates have: (1) an ability to apply knowledge of mathematics, science and engineering, (2) an ability to design and conduct experiments, as well as to analyze and interpret results, (4) an ability to function on multi-disciplinary teams, (5) an ability to identify, formulate and solve engineering problems, (7) an ability to communicate effectively, (11) an ability to use the techniques, skills and modern engineering tools necessary for engineering practice.

Manufacturing Engineering Track-Specific ABET Outcomes are: Engineering graduates have: (M1) proficiency in materials and manufacturing processes, understand the influence of manufacturing processes on the behavior and properties of materials, and (M5) had laboratory experience, which enable them to measure manufacturing process variables and make technical inference about the process.

ABET outcome assessment for ENGR 2180 is shown in Figure 2.

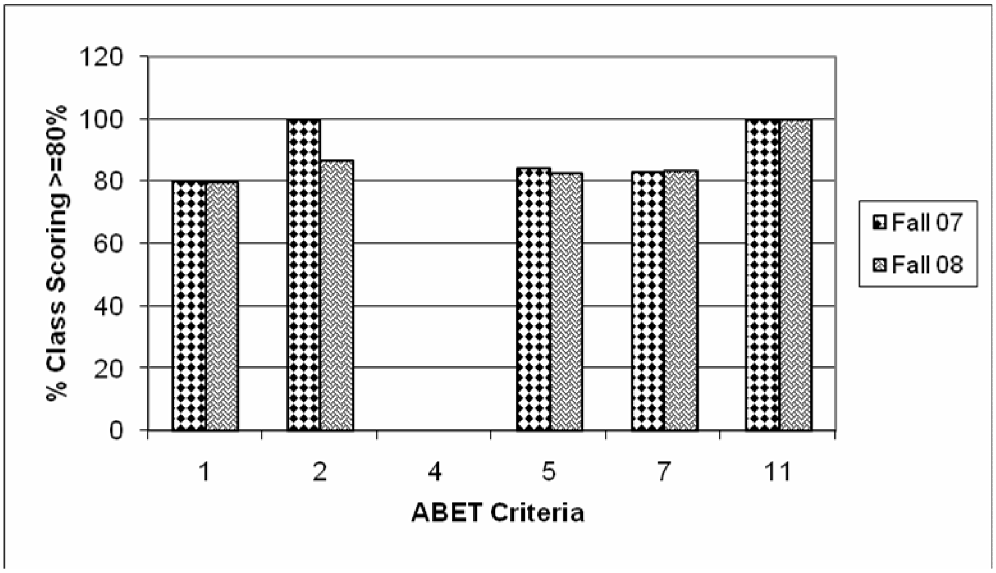

Figure 2: Class performance with respect to ABET outcomes. (The current benchmark for class performance is 80%).

Most of the outcomes assessment criteria are being met except Outcome #4, which was not assessed in any of the terms, and therefore no data is available for this outcome. It appears form the data shown in Fig. 2 that the students found it more challenging to conduct experiments and interpret results to solve engineering design problems (as measured by ABET Outcome 2). Track-specific outcomes assessment data (not shown here) for both the terms was also found to be satisfactory.

4.3 Student Feedback

Finally, the end-of-term student satisfaction survey was conducted informally in the class. A few comments from the students selected from the surveys are given below:

- It was a fun and informative class overall.
- I enjoyed the class and the breadth of knowledge presented greatly enhanced my understanding of engineering.
- I learnt a lot from this course. I actually was able to apply some of this knowledge at a materials science fair for high school kids. I had to give demos of tensile testing and talk about examples from an impact test. What I learned from the course allowed me to teach the high school kids some important aspects of materials science.

And on a different note, something to think of for future teaching:

- The instructions given for the research report were vague

5. Summary

The challenge to teach an introductory material engineering course to non-majors (e.g. manufacturing engineers) is complex due to the subject matter that spans across disciplines of physics, chemistry, mathematics and manufacturing engineering. A top-down approach is described in this paper for dealing with these many complexities in an effective manner. The innovative ideas in this approach include the extensive use of materials design challenges and research tasks conducted by the students on contemporary materials research topics. Other successful teaching methods developed previously such as incorporating modern web-based, multi-media resources, materials databases, model building, conference participation, and hands-on laboratory experiences have been retained. Through the implementation of this top-down approach in the Fall '08 term, it was found that the student performance in the course and ABET outcomes assessment improved significantly as compared to the previous years. The new approach seems to enhance student understanding of the subject matter and motivates them to utilize the materials knowledge for product and process design tasks during rest of their engineering degree curriculum.

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