# 2006-154: AN INNOVATIVE TWO-TIERED APPROACH TO TEACHING ENGINEERING MATERIALS TO MANUFACTURING ENGINEERING STUDENTS

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# An Innovative Two-Tiered Approach to Teaching Engineering Materials to Manufacturing Engineering Students

## 1. Nature of the Problem

An introductory materials engineering course is expected to lay the foundation for providing insights into materials behavior so that manufacturing engineers are able to select, optimize, and control appropriate manufacturing processes. However, the task of teaching a materials engineering course is complex and difficult due to the following facts:

- The subject matter draws upon various disciplines such as physics, chemistry, and mathematics.
- Students may lack the ability to visualize and rationalize about the abstract three-dimensional arrangement of atoms that make up the structure of materials[1)].
- Behavior of materials is influenced by phenomena occurring at varying length scales; e.g., nano-scale atomic structure, meso-scale at the level of individual crystals, micro-scale at the level of polycrystalline, multiphase materials to bulk scale at the level of thousands of tons of a material. Students find it difficult to navigate through the correlations between the differing levels of structural detail with materials properties and performance.
- The relationships between processing, microstructure and properties are highly non-linear. Consequently, considerable material data exists in form of complex diagrams (e.g. a variety of X-Y plots depicting process – property relationships, equilibrium diagrams, continuous cooling transformation - CCT and Time - Temperature – Transformation - TTT diagrams) that are difficult read, interpret and apply.
- The spectrum of available materials broadens every day from well-established materials such as iron, copper, and aluminum alloys to hybrid, intelligent, bio, and nano materials.
- The appropriate choice of material for a given application is becoming complex due to contemporary additional requirements of the total life-cycle costing approach, which includes the energy, environmental, and recycling considerations.

Additionally, there are generic factors that add to the above-mentioned inherent challenges in teaching materials science. These factors are depicted in Figure 1.

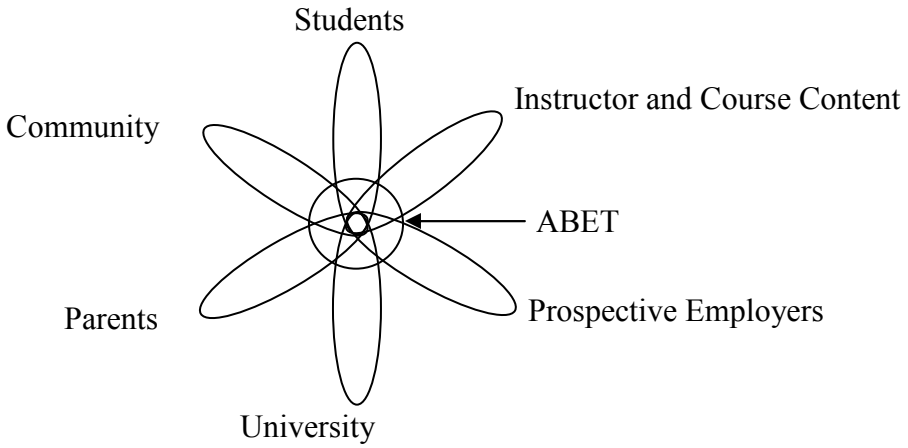


Figure 1: Stakeholders in the teaching – learning environment.

As shown in Figure 1, there are many stakeholders in the modern teaching – learning environment. As a consequence, the expected quality of teaching is determined not only by the course content and delivery, but also the need to meet the expectations of the parents, community, student, instructor, university administration, ABET, and finally the prospective employers of engineering graduates. The ABET outcomes expectations are depicted as a superset in Fig. 1, thereby intersecting of all of these factors. It is an ***assumption*** that all the sets intersect and all are well contained within the ABET superset. More importantly, it is necessary to examine this assumption so that a well-designed template is derived from such analysis in order to teach materials science in a way that maximizes the quality of teacher – student interaction. It is the expectations by the various stakeholders depicted here that form the basis for the development of a new teaching approach; the expectations of these constituents are discussed in the following section

## 2. Differing Expectations

The current-age students have grown up in the computer age and, therefore, are most familiar with computer-based learning tools. They expect the lectures to be power-point based attractive presentations that they can download and print so they will not have to take notes. These students prefer computer simulations whereby results can be obtained quickly at the click of a mouse.

***The student*** expectations are summarized as:

- Power-point based presentations
- Hands-on experiences that they can use in co-op programs or jobs
- Lectures that use multi-media: internet, videos, class exercises, discussions, and case studies

- Informal classroom learning environments where diversity is accepted

Most of the students at RMU are regional, commuter students who work while attending school, which means that the flexibility for organizing activities outside of the scheduled class times is quite limited. In addition, students often say, "Our friends in arts and management have fun and still get A grades, why do we have to work so hard to get good grades in engineering?" In other words, some students feel that the faculty sets the bar too high in engineering, and therefore the grade does not always reflect the hard work they put into the learning process. Further, the lecture rooms are typically equipped with computers for student use. Whereas this may be an advantage at times, the availability of computers often interferes with teacher interaction and can be a source of student distraction.

***The prospective employers*** expect several qualities in a fresh engineering graduate. Hildeman[2)] suggests one set of expected attributes from a graduating manufacturing / materials engineer as follows:

- Possesses verbal and written communication skills
- Thinks in terms of value creation
- Has hands-on, practical experience
- Pays attention to detail
- Has a high level of energy, passion and drive
- Takes initiative and assumes leadership roles
- Thinks globally
- Has a strong technical education and analytical skills
- Applies critical fundamental thinking to solve problems
- Is a team player in a diverse, multi-cultural workplace
- Establishes a strong network
- Pursues continuous learning
- Promotes safety, health and environmentally sustainable development

***The university administration*** has expectations from the faculty in accordance with ABET criteria. These expectations include:

- Course content and delivery is aligned with program outcomes.
- Faculty course assessment reports (FCARs) are prepared on time and any suggested modifications are incorporated next time the course is delivered so that the loop is closed.
- Faculty design student assessment tasks that facilitate quantitative measurement of ABET outcomes
- Performance benchmarks are achieved in course and program outcomes. For example, the RMU benchmark states that at least 80% of the class obtains 80% or better marks in ABET outcomes assessment tasks.

***Parents*** would like to see the following:

- The university offers a safe and supportive environment for learning.
- Student motivation is increased so that students complete the degree requirements.

- There is value for their money in terms of student success.

***The greater community*** expects modern engineers have the following skill set:

- Awareness of ethical responsibilities
- Attention to energy conservation, environmental protection, and sustainable development
- Ability to design and develop economical and better products for consumption
- Well-developed personalities including communication and social skills

Finally, ***the body of knowledge*** contained in a course and the expert knowledge of the instructor requires that certain topics be taught with greater emphasis than others. Further, it is expected that appropriate teaching methodologies be utilized to assure the accomplishment of course outcomes. As applied to materials engineering, the following topics are identified:

- Crystal structures: physical models
- Diffusion phenomenon: mathematical models and problem solving, examples of applications, experimental observations on the rate of diffusion of ink in water
- Phase diagrams: interpretation skills
- Mechanical properties: laboratory experiments on tension test, impact test, hardness, heat treatment
- Materials selection: study of common objects and designs – cups and saucers, cutlery, door knobs, skate boards, bicycles, cars, etc.
- Failures: fracture generated from different tests

Some topics such as phase diagrams and atomic bonding are very important, but they are complex to teach and not easy for students to understand. Theses, of course, require more time, effort and homework problem sets to get the message across. As a result, it is not always possible to appropriate equal amounts of teaching time and assessment tasks to meet all of the ABET outcomes listed for the course. This balancing act then becomes quite a challenge.

To address this challenge, a two-tier approach was developed and delivered during the Fall 05 term at Robert Morris University to deal with the differing expectations of the stakeholders in the teaching/learning environment as described in Figure 1. This approach is further discussed in this article.

## 3. The Two-Tier Approach

The first tier of the teaching plan, called the '***essential teaching plan***' includes all of the essential teaching elements. These elements consist of the following:

- Set teaching method(s): The options are lecture, discussion, tutorial, laboratory, mutli-media resources. For different topics, the instructor identifies appropriate teaching methods and plans lecture schedules accordingly. For example, a top-down approach was adopted where bulk materials, their properties and applications are studied first, which is subsequently followed by the more traditional approach of studying materials structures at nano, meso and micro scales. The CES EduPack[3)] software was employed to ask students to search for

materials used for door knobs, ear-rings, engine valves, car body panels, castors, air plane frame, lego pieces, heat shields, etc. Students completed ten hands-on tutorials to become familiar with the use of the software package. Tutorials included various tasks such as searching, sorting and selecting materials for specific design requirements and to generate reports.

- Plan student deliverables: Identify homework problem sets including some of the questions from the FE examination to assure that ABET outcomes are addressed along with the primary objectives of knowledge enhancement.
- Plan laboratory work Plan for senior / graduate student assistants and train them, if required. Obtain test samples and prepare safety instructions, test procedures, equipment operation, and ensure that test equipment is functioning well. In the present case, students conducted tension, hardness, and impact testing of common engineering alloys such as low carbon (mild) steel, medium carbon (forging) steel, 70 – 30 brass, 6061 Aluminum and 304 stainless steel. Impact tests were conducted at three different temperatures - 32, 60 and 232 $^{o}$F – for each alloy. Students wrote a detailed laboratory report that included test procedure, details of sample geometry, compilation of test data and subsequent data analysis to make correlations between alloy composition and test variables on the properties of materials.
- Identify case studies, discussion points, controversies and current directions to enhance a continuous learning approach and to make the course content more interesting--a high tech broom or golf club catches attention!
- Obtain and study past FCAR: Take note of any suggestions made in the past FCAR for course improvement.
- Prepare administrative materials such as course schedule and attendance sheet.

The second tier, termed the '***course enrichment plan***', describes a range of innovative ideas that are in-tune with the contemporary teaching – learning environment and that add value to materials education. These ideas include the following:

- Using multi-media resources such as educational videos and recorded interviews to give an overview of the materials world. For example, a compact disk made by Struers (Struers is a major manufacturer of metallurgical laboratory products, see www.struers.com for more information) was obtained that presented the history of materials evolution right from the pre-historic times to the present age. In addition, simulations provided on the instructor's resources compact disk (IRCD) were shown and discussed on various topics such as solid solubility of carbon in steel, diffusion, and dislocation motion were shown and discussed.
- Accessing the Internet to obtain freely-available materials information and simulation programs; e.g., MATTER project in UK (www.matter.org.uk). The web site contains information, property data, application notes, on-line experiments, case studies on a number of industrially-significant aluminum and ferrous alloys. The students were asked to explore this website and subsequently take a quiz (also available on the same website) during one of the laboratory sessions.

- Inviting professional materials engineers, industrial advisory board members and research faculty to give presentations. Several professionals and academic members were invited to give talks or conduct hands-on activities in the classes, which developed greater insight into the challenges and rewards in the life of practicing materials manufacturing engineers. A seminar series was organized at RMU and several distinguished speakers gave talks in the class. For example, Prof. John Campbell (University of Birmingham, UK) discussed the fundamental mechanisms for the creation of defects in cast metals in his two lectures. The concepts presented included cracks generated by turbulence in the liquid metals leading to failures of several kinds, including porosity, hot tearing or failure by cracking in service. Dr. Gregory Hildeman (Alcoa) presented an overview of the growth of the aluminum industry, evolution of Alcoa and examples how aluminum is used in products and applications. From a career view point, key attributes of what makes a good materials and manufacturing engineer in the aluminum industry were also discussed.
- Drs. Jacobson and Frollini from Carnegie Mellon University delivered a hands-on course where students conducted several experiments with polymers. The students shrunk polymer sheets to half their original size in a kitchen toaster, made toys such as zoom balls (polystyrene), observed a large quantity of water being absorbed by a very tiny amount of polymer powder (polymer gels), played with synthetic, water-soluble (sodium polyacrylate) and water-insoluble packing beans, studied polypropylene that is used in the control of oil spills and so on. The students enjoyed this class immensely.
- Integrating activities such as model building through the use of foam balls, magnets, paper clips etc.: Students made the crystal structures of metals and polymers, studied the geometry to understand how atoms come together to make bulk materials.
- Visiting industrial sites of conventional heavy industries (e.g. steel plants) and emerging industries (biomedical equipment).
- Attending sessions at professional conferences and trade exhibits: Students attended Materials Science and Technology ’05 conference, trade exhibition, and a four hour Materials Camp organized by ASM. Materials camp consisted of eight displays: bio-, and cryogenic- materials, manufacturing engineering, non-destructive testing, corrosion, plastics, mechanical testing and shape memory alloys. Students gained valuable experience through their participation in the hands-on exhibits at these displays. The students also enjoyed the exhibit in the MS&T trade show by the *Pittsburgh Artist – Blacksmiths Association*, where an induction coil was set up to heat bars of mild steel to red heat. The bars were subsequently hand-forged by the blacksmiths into wrought iron art pieces.

## 4. Effectiveness of the Two-Tier Approach

The two-tier approach was implemented at Robert Morris University during, and the achieved results were compared with those of the fall ’04 term. The student performance in the Fall ’05 term is shown in Table 1.

Table 1: Student final grade distribution for ENGR 2180, Fall 05 semester.

| Grade | Number of Students | Percentage |
|---|---|---|
| A | 9 | 52.9% |
| B+ | 4 | 23.5% |
| B | 2 | 11.8% |
| C+ | 1 | 05.9% |
| F | 1 | 05.9% |

A: ≥ 90%; B+: 85 – 89%; B: 80 – 84; C+: 75 – 79; C: 70 – 74%; D: 60 – 69%; F < 60

The students performed well during the Fall 05. This performance was significantly better than the Fall ’04 term, where 50% of the class obtained C or lower grade. According to the existing course description, the following ABET outcomes were expected to be satisfied by this course:

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

The various student assessment tools employed focused on evaluating these outcomes to varying degrees as shown in Figure 2.

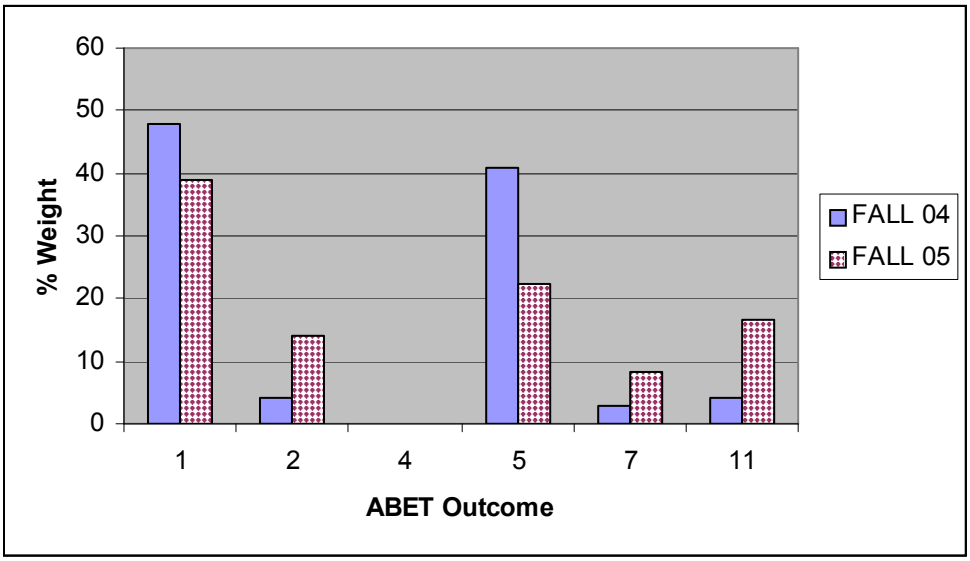


Figure 2: Relative importance placed on assessing applicable ABET outcomes in Fall ‘04 and Fall ‘05.

It can be seen from Figure 2 that a heavy emphasis was placed on assessing ABET outcome 1 and 5 (application of the knowledge of math, science and engineering and problem solving) in Fall ’04. While this is both natural and appropriate for the body of knowledge being taught, the remaining applicable outcomes were not assessed well in Fall ‘04. On the other hand, during the Fall ’05 term, the two-tier approach and the attention paid to the design of the assessment tasks has resulted in a more uniform distribution of the importance given to the different ABET outcomes assessments. The listed Outcome 4 (multi-disciplinary team) has not been assessed on both the occasions.

The student performance for the Fall ’05 term in terms of ABET outcomes assessment is shown in Figure 3.

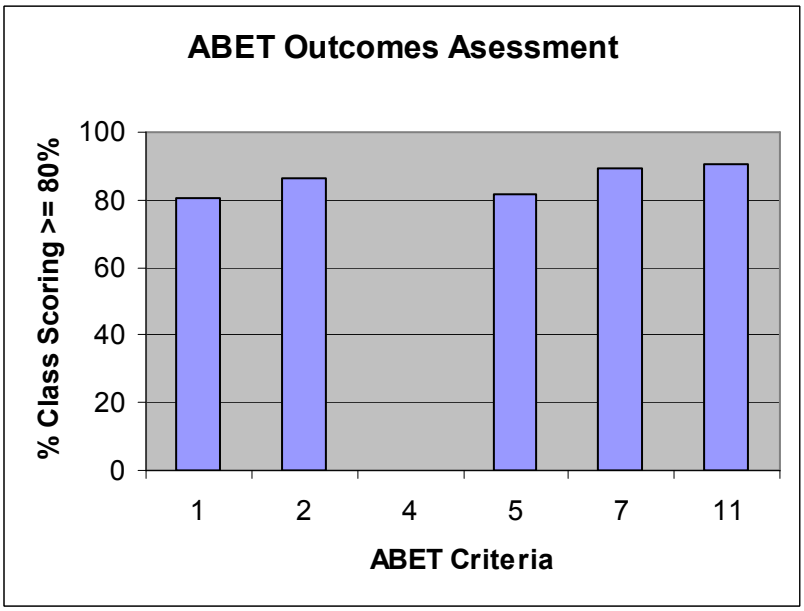


Figure 3: Class performance with respect to ABET outcomes. (The current RMU-designated benchmark for class performance is 80%).

This chart demonstrates that the RMU-benchmark is met for all applicable ABET outcomes criteria (except for Outcome 4, which was not assessed). Figure 3 also shows a scope for improvement in outcome 1, i.e. more efforts are needed to enhance students’ application of the knowledge of math, science and engineering. This is valuable feedback for the instructors who teach the freshman year core courses in physics, chemistry and mathematics.

## 5. Summary

The challenge to teach an introductory material engineering course to manufacturing engineers is complex due to the subject matter that spawns across disciplines of physics, chemistry, mathematics and manufacturing engineering. As one endeavors to expose the students to the mind-boggling array of conventional and modern materials at atomic levels to bulk structural levels, their intrinsic and extrinsic properties,

their eco-economic impact, etc., it becomes a juggling act to give justice to the multi-dimensional aspects of materials education. In addition, the expectations of the various stakeholders in the teaching – learning transaction are different and it is necessary to address their needs. Simultaneously, it is imperative to meet the needs of all stakeholders in the teaching-learning process.

A two-tier approach is described in this paper for dealing with these many complexities in an effective manner. The innovative ideas included in this approach adopt a top-down approach to teaching, which includes designing student assessment tasks with a view to align them well with ABET outcomes assessment tasks, and incorporating modern teaching tools such as web-based, multi-media resources, materials databases, model building, conference participation, and hands-on laboratory experiences. Through the implementation of this two-tier approach in the Fall '05 term at Robert Morris University, it was found that the student performance in the course assessment and ABET outcomes assessment improved significantly as compared to the previous year. The new approach also helped identify activities that are working well to enhance student understanding of the subject matter and to identify areas for further improvement.

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