Integrating Real World Situations into an Introductory Course in Engineering Materials

Priya T. Goeser[1] and Cameron W. Coates[2]

Abstract – Introduction to Engineering Materials is a course in which students study the fundamentals of materials processing, materials structure, material properties and materials performance as well as the relationships between these concepts. Many students view this course as a collection of abstract concepts and terminology with little application in the real world. This work describes the implementation of projects and case studies in the course in order to improve student appreciation for practical applications. The authors outline exploratory project questions that are used to stimulate student interest in course material. Student surveys are used as assessment tools to determine the effectiveness of these projects. Assessment results provide evidence that students develop a better understanding and appreciation of concepts, and develop their problem solving and critical thinking skills. The results also indicate that the teamwork involved improves their soft skills such as professional communication and team working abilities.

Keywords: Engineering Materials, Case Studies, Real World Applications

INTRODUCTION

Most engineering curricula follow the engineering education model based on traditional lecture-based courses. Only recently, have attempts been made to introduce team learning through projects and case studies. These endeavors have had reasonable success [4], [7]. While the traditional format has proven effective over the past fifty or so years, engineering employers of recent university graduates find that many of the students are lacking the breadth of knowledge and soft skills that are important for competency in their fields [8]. These generic or soft skills such as professional communication and team working/networking abilities are crucial to students as they transition into their careers in engineering [5]. In addition, the exclusive use of lectures has created a passive learning environment that does little to cultivate intellectual curiosity and self-led learning abilities [2], [8].

The Engineering Studies Program at Armstrong Atlantic State University (AASU) is a part of the regional engineering program in which students complete their first two years of the engineering curriculum at AASU and then transfer to the Georgia Institute of Technology to complete their engineering degrees. The current program enrollment is approximately 250 students with 75 of those declared as mechanical engineering majors.

Many students at Armstrong Atlantic State University view the Introduction to Engineering Materials course as a collection of abstract concepts and terminology with little application in the real world. The extensive course syllabus provides little opportunity to demonstrate and study its relevance to real world situations. Hence, there exists a gap between the theoretical concepts taught in this course and their use in real world applications. This contributes to the challenge to maintain a high level of interest, enthusiasm and information retention among the students.

---

[1] Assistant Professor, Engineering Studies Program, Armstrong Atlantic State University, 11935 Abercorn St., Savannah, GA 31419, Priya.Goeser@armstrong.edu

[2] Assistant Professor, Engineering Studies Program, Armstrong Atlantic State University, 11935 Abercorn St., Savannah, GA 31419, Cameron.Coates@armstrong.edu

There are several approaches to address this concern in engineering materials and similar courses. One approach used to bridge this gap is to incorporate laboratory exercises to reinforce concepts. For example, the faculty at the Mississippi State University have introduced a semester long laboratory project to compliment their course in engineering materials [9]. The faculty at North Carolina A & T State University have used several supplementary learning methods to enhance their materials science course. These include multidisciplinary learning, the use of a materials concept inventory, service learning through tours and lectures and hands-on experience [6]. It is well known that hands-on laboratories are an essential part of engineering education where students are introduced to data analysis, report writing, finding empirical correlations between experimental variables and data and to validate theories. However, such laboratories are not always available due to the lack of space, high costs and time constraints.

Another approach implemented at Western New England College is the use of a materials-selection-software as the primary tool to analyze materials selection applications based on current news events [11]. In view of the fact that general chemistry is the prerequisite to most materials science courses, faculty at the Worcester Polytechnic Institute collaborated with the chemistry department to augment general chemistry laboratories with concepts on material properties and applications [3].

A comparative assessment of two instructional formats of an introductory materials science course – a traditional, lecture based format vs. an active, student learning teams, teacher as manager format shows that such courses do lend themselves to a non-traditional, project based format [2]. This paper describes the introduction of projects and case studies in a traditional, lecture-based introductory course in engineering materials. The main objective is to improve student understanding and appreciation of the course material. Students also learn the art of in-depth research and self-study, and develop soft skills such as communication of research and results in a professional style and team working abilities.

The following sections present a brief description of the course under consideration, a detailed description of the projects and case studies introduced in the course, a summary of assessment results, and conclusions of the authors' experiences.

COURSE DESCRIPTION

Introduction to Engineering Materials (ENGR2000) is a 3-credit hour lecture course taken primarily by Mechanical Engineering students as a core requirement in their sophomore year. Civil and Electrical Engineering students take the course as an elective in their sophomore or junior years. The course has been taught using a traditional, in-class lecture-based model since Spring 2005 with assignments and written exams used as testing tools. The prerequisites for the course are Chemistry I (General Chemistry) and Physics I (Calculus-Based Principles of Physics).

The main objective of the course is to study the fundamentals of materials processing, materials structure, material properties and materials performance as well as the relationships between these concepts. Some of the specific topics covered are: atomic bonding, crystalline structures, dislocations, diffusion, phase diagrams, structural transformations, mechanical, electrical and thermal properties, materials selection and design. All topics have a focus on the three primary classifications of engineering materials: metals, ceramics and polymers.

After successful completion of the course, students are expected to be able to:

- Analyze and predict material structure at the atomic, molecular and macroscopic levels
- Analyze and predict material performance based on material properties
- Perform design, safety and failure analysis for specific materials
- Analyze and predict materials for materials selection and design applications

This course also lays the foundation for other advanced engineering courses such as Strength of Materials and/or Mechanics of Deformable Bodies. Students take these courses in their junior and/or senior years at the Georgia Institute of Technology. It is also noted here that the Introduction to Engineering Materials course is offered once every academic year at Armstrong Atlantic State University and has an average enrollment of 15 - 20 students.

COURSE PROJECTS

Three projects were introduced in the course during the Fall 2007 semester. The students worked in teams of four on these projects over periods of three - four weeks each. Each of the projects had a sample list of topics/options with applications from a wide variety of engineering fields. The first two projects had two phases each: the research phase and the oral presentation phase. The last project had an emphasis on problem solving and analysis for materials selection and design and consisted of the research phase, the problem-solving phase and a final written report. Further details on the projects are presented in the following sections.

First Project: Material Selection and Design

The first project, on material selection and design was given to the students during the third week of class. The main objective of this project was to introduce students to the comprehensive, analytical and deductive process involved in selecting optimum materials for a specific application and/or design. It was expected that interest and enthusiasm for course material would increase if students investigated realistic and credible applications.

The following are some of the topics given as part of this project [10]:

- Consider the common household component in a light bulb. Identify various critical components of this item. Determine the material selected for each critical component.
- Name the important factors in selecting materials for the frame of a mountain bike. Steel, aluminum and titanium alloys have all been used as the primary metals in the structure of a bicycle. Determine the major weaknesses and strengths of each. The more modern bikes are made of advanced composites. Explain why and identify a specific composite materials used in the structure of a bike.
- Name the important criteria for selecting materials to use in protective sports equipments such as a helmet. Identify materials that would satisfy these criteria. Why would a solid metal helmet not be a good choice?
- Determine the required properties of the materials used as the heat shield in the structure of a space shuttle. Identify materials that would satisfy these requirements. Why would titanium alloys not be a good choice for this application?
- Nickel base super alloys are used in the structure of aircraft turbine engines. What are the major properties of this metal that make it suitable for this application?

The teams were required to do research and give an oral presentation on one of the above topics. However, the different teams were encouraged to work on different topics in order to expose the entire class to a diverse set of applications.

The following are some of the issues addressed by the students in their research:

- What are the main criteria for material selection for the specific applications?
- Compare the properties of four - five different materials and make recommendations for the final design.
- Compare the final recommendation with current materials used for the application.

Student feedback indicated that this project increased their interest and enthusiasm for the remainder of the course material. In addition, students were also introduced to current and emerging trends in engineering materials such as composite materials, smart materials and nano-materials.

Second Project: Case Studies on Material Failure

The second project was a case study on historical engineering disasters caused by material failure. This was given during the ninth week of classes (mid-semester) after completion of topics such as mechanical properties of materials, material fatigue and failure analysis.

The following are some of the historical engineering disasters studied by the students:

- Comet aircraft crashes (early 1950s)
- Aloha airlines Boeing 737-200 Accident (1988)
- Chicago DC-10-10 Crash (American Airlines Flight 191, 1979)
- Japan Airlines Boeing 747 SR Crash (1989)

Students were required to do extensive research (via internet, books, articles, etc.) and give an oral presentation on the case study selected. Some of the questions addressed by the students were:

- Where and when did the material fail?
- How did the material fail?
- Why did the material fail?
- Who was at fault for this failure? Why?
- What change(s) in the design/material selection would you recommend for this application in the future?

The case studies from the ‘real world’ helped develop an appreciation in the students for the usually tedious design and safety analysis process. Fundamental concepts of failure analysis such as the use of S-N curves for fatigue life prediction, crack propagation, stress raisers in fracture mechanics, etc. were reinforced as the students worked through this project. Students were also introduced to the important roles organizations such as the American Society for Testing and Materials (ASTM) and the Federal Aviation Administration (FAA) play in the standardization of testing, safety and design procedures.

The oral presentations at the end of the first and second projects proved to be beneficial in two ways: they exposed the entire class body to the different topics assigned and they provided an opportunity for the students to develop professional communication skills.

Third Project: Material Selection, Problem Solving, Analysis and Design

The third project was given to the students during the last four weeks of the semester. This last project required an in-depth knowledge of the concepts learned in the course and hence can be considered as the culmination of materials selection, problem solving and analysis for design and failure. Student teams were required to select one of three options, all of which combined elements of stress analysis with material selection, design and failure.

The first two options are based on problems covered in the textbook [1]. The first option involved performing a stiffness to mass performance analysis as well as cost analysis in order to select the best candidate among five materials suitable for a cylinder subjected to torsional stress. Students were provided a table of five materials and their densities. They were then required to add a column to this table to include the stiffness performance index P, given by:

$$P = \frac{\sqrt{G}}{\rho} \qquad (1)$$

where G is the shear modulus and ρ is the density. Students also had to research the cost per unit mass of these materials in order to rank these materials both on the basis of mass of material required and material cost.

Students explored questions such as:

- Had the five materials not been given, how would one decide on candidate materials and then narrow the list down to five?

- Since this design is for a shaft in torsion, how would the application of the shaft affect the material selection? For example, weight and ability to withstand a wide temperature range may be more important for drive shafts in military helicopters compared to the axle of an automobile.

- After considering cost, stiffness, mass and application, what other important factors, if any, are being neglected? For example, manufacturability, environmental laws for disposal or transport of material, compatibility with surrounding components etc. may also be significant.

The second option involved the determination of the maximum tensile load on an automobile valve spring. Figure 1 shows the schematic of a simple helical spring used for this analysis.

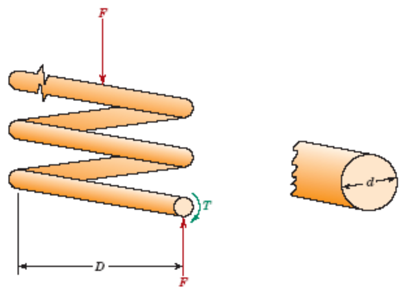

Figure 1. Schematic diagram of a helical spring [1]

The spring deformation and the maximum possible tensile load before plastic deformation were calculated using equations (2) and (3):

$$\frac{\delta_s}{N_c} = \frac{8FD^3}{d^4 G} \qquad (2)$$

$$\tau = \frac{8FD}{\pi d^3} K_w \qquad (3)$$

where D is the coil center to center distance, d is the circular cross sectional diameter, F is the applied compressive force, N_c is the number of effective spring coils, G is the shear modulus, δ_s is the maximum deflection and τ is the shear stress. K_w is a force independent constant that is a function of the ratio D/d given by:

$$K_w = \left(\frac{D}{d}\right)^{-0.14} \qquad (4)$$

Students explored the following questions for this option:

- Why is the ratio D/d isolated in equation (3)?

- Why aren't all the coils in the spring active?

- When and why would one want to increase/decrease the number of spring coils?

- Are there any other failure modes, or do springs always fail due to high shear stress?

The third option involved failure analysis of a primary structural component for the vertical stabilizer of a commercial aircraft using concepts from fracture mechanics. This was a modification to a small component of an actual failure analysis investigation performed by one of the authors. This problem required that students utilize equations derived from fracture mechanics in order to determine whether a crack found during routine inspection would have led to complete structural failure shortly thereafter. The basic crack geometric parameters: crack length, depth and plate width, were provided as a simulation of actual measurements taken. Students had to determine the stress intensity factor, K_1, based on these simulated measurements using equation (5) and compare its value to the fracture toughness, K_c, of the material.

$$K_1 = C\sigma \frac{\sqrt{\pi a}}{\Phi} \qquad (5)$$

In equation (5), C and Φ, are functions of the crack geometry, a is the crack length and σ is the applied stress. The applied stress was assumed to be $0.8\sigma_{ys}$ where σ_{ys} is the yield strength. The students then had to examine how their results would change if all measurements were at their maximum error tolerance of 20 % and also determine which physical parameter measurement had the greatest influence on the fracture toughness. Finally, they were expected to make recommendations on whether to continue using the existing material or select a different material based on the fracture toughness comparison and the sensitivity analysis performed.

Questions explored for this option included:

- What other tools are available whose use or implementation would corroborate the findings from fracture mechanics? For example, Scanning Electron Microscopic (SEM) images, microscopic images of microstructure, hardness tests and material spectroscopy to verify material constituents, stress analysis etc.
- Based on the location and use of this component, what other factors are important in the consideration of imminent failure due to a crack? For example, corrosion, temperature, fatigue, overload, etc.

The students were required to submit a written report after completion of this last project. It is noted here that of the four teams, one team worked on the first and second option and the other three teams worked on the third option.

ASSESSMENT

In order to assess the effectiveness of the projects in achieving the desired objectives, surveys were provided to the students after completion of the projects. A summary of results based on the students who completed the survey are provided in Table 1. It is observed that 75% of the respondents strongly agreed that the projects increased their enthusiasm and interest in the course and 92% of the respondents agreed or strongly agreed that the projects improved their understanding of course material. All respondents thought the projects allowed for better identification of course topics to real world situations and none found the projects too difficult or time consuming.

Questions	**Options**	**Fall 2007 results**
The projects helped me develop an enthusiasm and interest in the course.	Strongly Agree	9 out of 12
	Agree	3 out of 12
	Disagree	0
	Strongly Disagree	0
	Not Applicable	0
The projects helped me to better understand the course material.	Strongly Agree	4 out of 12
	Agree	7 out of 12
	Disagree	1 out of 12
	Strongly Disagree	0
	Not Applicable	0

Questions	Options	Fall 2007 results
The projects were too difficult and time consuming.	Strongly Agree	0
	Agree	0
	Disagree	9 out of 12
	Strongly Disagree	3 out of 12
	Not Applicable	0
The projects allowed for better identification of course topics to real world situations.	Strongly Agree	8 out of 12
	Agree	4 out of 12
	Disagree	0
	Strongly Disagree	0
	Not Applicable	0

Table 1. Survey questions and results for Fall 2007 (for 12 students)

Student general comments are shown in Table 2. The majority of student comments were positive. Two of the twelve students did not have time to meet outside class; one student thought the project grade should contribute more to the course grade given the research effort, while three were doubtful that the class would be able to complete the coursework specified by the syllabus given the additional amount of time required for the projects.

List any perceived advantages due to the inclusion of such projects in the course:	Number of similar responses
"research - getting familiar with industry data"	1
"getting contacts in the industry for future projects/jobs"	1
"helped make concepts much more clear and not so abstract"	5
"allows us to apply material learned in class to real world topics"	6
"projects help stimulate other interests and hobbies that involve topics in engineering materials"	1
"doing the projects helped me to understand how the theory actually applies to materials/material processing/material selection"	1
List any perceived disadvantages due to the inclusion of such projects in the course:	**Number of similar responses**
"did not count as much as they should have considering the amount of research, preparation and presentation"	1
"not completing the (maybe) required course material"	3
"need class time to work as a team. Didn't have time to meet outside of class"	2
Other comments/suggestions:	**Number of similar responses**
"interesting to see how new technology is developed from old technology"	1
"with any group work, there is the possibility that one or more persons will not participate equally. It is also difficult for a group of engineering students (busy) to meet all at once. This is very much like the real world."	1
"time management!"	1
"projects made the class more interesting"	2

Table 2. A summary of the comments/suggestions from the survey

The results of the surveys and student comments show success in this approach. In addition to benefits such as a better understanding and appreciation of concepts and course material, enthusiasm for learning, etc., the students also learned the fundamentals needed for scientific, productive and systematic research and improved their ability to perform independent study. Most of the students read and studied reference articles, book chapters and other material in addition to the textbook and lecture material for the projects. The instructor was available only for general guidance and evaluation of the projects.

The authors would like to specifically address the concern mentioned by students regarding completion of required coursework. It was observed at the end of the semester that this was not a problem, since only three class periods (two of which were used for the project presentations) were used for the projects. In addition, the chapter on material selection and design was extensively addressed by the last project and a good portion of the key concepts in material fatigue and failure was addressed by the case studies in the second project.

CONCLUSION

This work describes the introduction of projects and case studies in an engineering materials course that uses the traditional, lecture-based model. The main objective of this work was to develop student understanding and appreciation of concepts taught in the course. In addition to meeting this objective, students learned the art of in-depth research and independent study, and developed soft skills such as professional communication and team working abilities.

Although the sample size for the semester was small, the survey results indicate that these case studies and projects are likely to increase interest, enthusiasm and motivation to learn the course material. Based on the initial results, the authors are encouraged and plan to continue to implement projects and case studies in this course. If outcomes continue to be successful, the authors plan to extend this strategy to other courses such as Introduction to Engineering, Creative Decisions and Design and Fundamentals of Engineering Thermodynamics.

REFERENCES

[1] Callister, William, D. Jr, *Materials Science and Engineering: An Introduction,* John Wiley and Sons Inc., 2007

[2] Demetry, Chrysanthe and Groccia, James, E., “A Comparative Assessment of Students’ Experiences in Two Instructional Formats of an Introductory Materials Science Course,” *Journal of Engineering Education,* July 1997, pg 203 – 210

[3] Demetry, Chrysanthe, Gurland, Suzanne T. and Kildahl, Nicholas., “Building Bridges to Material Properties in General Chemistry Laboratories: A Model for Integration Across Disciplines,” *Journal of Engineering Education,* October 2002, pg 379-386

[4] Dym, C.L., “Learning Engineering: Design, Languages, and Experiences,” *Journal of Engineering Education,* April 1999, pg 145 – 148

[5] Hoddinott, John and Young, David, “Generic Skills Teaching in Materials Science and Engineering,” *Journal of Engineering Education,* October 2001, pg 707 – 711

[6] Kumar, Dhananjay, Pai, Devdas, Waters, Cindy, and Sankar, Jagannathan, “Supplementary Learning Methods in Materials Science Education,” *Proceedings of the ASEE Annual Conference,* Honolulu, Hawaii, 2007

[7] Lawrence, Thomas M., “Using Case Studies to Bring Real World Situations into the Engineering Course Learning Environment,” *Proceedings of the ASEE Southeast Section Conference,* Tuscaloosa, Alabama, 2006

[8] Raju, P.K. and Sankar, Chetan, S., “Teaching Real-World Issues through Case Studies,” *Journal of Engineering Education,* October 1999, pg 501 – 508

[9] Schneider, Judy, “Integrating Materials Science into the Mechanical Engineering Curriculum,” *Proceedings of the ASEE Southeast Section Conference,* Tuscaloosa, Alabama, 2006

[10] Smith, William, F. and Hashemi, Javed, *Foundations of Materials Science and Engineering,* McGraw-Hill, 2006

[11] Vollaro, Mary, “Materials Selection Exercises Based on Current Events,” *Proceedings of the ASEE Annual Conference,* Honolulu, Hawaii, 2007

Priya Thamburaj Goeser

Priya Thamburaj Goeser is an Assistant Professor of Engineering Studies at Armstrong Atlantic State University, Savannah GA. She received her Ph.D. in mechanical engineering from the University of Delaware in 2001. Her current research interests are structural health monitoring, functionally graded materials and innovative teaching methods in engineering education.

Cameron W. Coates

Cameron W. Coates is an Assistant Professor of Engineering Studies at Armstrong Atlantic State University, Savannah GA. He received his Ph.D. in aerospace engineering from the Georgia Institute of Technology in 2001. His current research interests are structural mechanics, structural health monitoring and biomechanics of bone tissues.