AC 2009-313: REDESIGNING A JUNIOR-LEVEL MATERIALS PROCESSING LABORATORY COURSE TO AID STUDENTS IN APPLYING THEORY TO PRACTICE

Diane Folz, Virginia Tech

Diane Folz is a Senior Research Associate and Laboratory Instructor in the Department of Materials Science and Engineering at Virginia Tech. She also is the faculty advisor for the Material Advantage Student Professional Organization and of the Journal of Undergraduate Materials Research (JUMR). In addition to teaching the materials processing laboratories, she mentors at least one team each year in their senior capstone project.

Christine Burgoyne, Virginia Tech

Christine Bala Burgoyne is the Assistant Director and Instructor of the Communications Program for the Departments of Materials Science and Engineering (MSE) and Engineering Science and Mechanics (ESM). Concurrent to this appointment, she serves as the publications liaison for MSE and the newsletter editor for ESM. She has an M.A. in English from Virginia Tech and B.A. in English Studies: Language from the University of the Philippines. Prior to her appointment, she was a member of the junior faculty at the University of the Philippines, Department of English and Comparative Literature, where she taught freshman composition and literature, introduction to linguistics, and phonology and morphology.

Janis Terpenny, Virginia Tech

Janis Terpenny is an Associate Professor in Mechanical Engineering and Engineering Education, and an affiliate faculty of Industrial & Systems Engineering at Virginia Tech. She is Director of the Center for e-Design, a multi-university NSF I/UCRC center. Her research focuses on methods and representation schemes for early design process and on engineering design education. She was previously faculty at the University of Massachusetts and worked at General Electric (GE), including the completion of a two-year management program. She is a member of ASEE, ASME, IIE, and Alpha Pi Mu and is the Design Economics area editor for The Engineering Economist and the Associate Editor for the ASME Journal of Mechanical Design.

Richard Goff, Virginia Tech

Richard Goff is an Associate Professor and Assistant Department Head of the Department of Engineering Education in the College of Engineering at Virginia Tech. He is also the Director of the Frith Freshman Engineering Design Laboratory and the Faculty Advisor of the VT Mini-Baja Team. He is actively involved in bringing joy and adventure to the educational process and is the recipient of numerous University teaching awards.

Re-designing a Junior-Level Materials Processing Laboratory Course to Aid Students in Applying Theory to Practice

Abstract

A junior-level materials engineering laboratory course has been re-designed to broaden the experiences of undergraduates in areas such as teaming and collaboration, written and oral communication skills, problem solving and the engineering design process. The re-design also incorporates more modern ceramic engineering processing methods. It is anticipated that the re-designed course will better prepare students to succeed; the premise being that providing such learning opportunities sooner and more often will improve student knowledge and confidence in applying theory to practice. This paper reports on the re-designed course and its effectiveness in meeting the learning outcomes.

The course is built on a prerequisite laboratory in which characterization methods were introduced through the evaluation of metals in a semester-long evaluation project. In the course under discussion, various processing methods were taught in the first few weeks, after which a seven-week design project based on one or more of these techniques was developed by teams consisting of three to five students. The problem presented to the students was to develop a project that illustrated the impact of processing on the properties of the materials. Teams were required to design both the technical and managerial aspects of the project. The teams were evaluated through the use of two written reports, periodic class presentations (evaluated by both the students and the instructor) and a final report prepared in the form of a journal paper. Student authors were given the opportunity to submit their manuscripts to the *Journal of Undergraduate Materials Research (JUMR)* for consideration. The assessment of individual student performance was in the form of quizzes, teammate assessment and class participation.

In addition to assessing the impacts on student learning and engagement for the re-designed course, this paper also reports on future plans to conduct follow-on research to assess the impacts the re-designed course may have on the senior year capstone design experience.

Introduction

The beginning of the 2006 academic year marked the first semester of a re-design of the curriculum in the Department of Materials Science and Engineering (MSE) at Virginia Tech to consolidate three individual laboratories into two. The original three courses focused on individual materials classifications (polymers, metals and ceramics) and the two new courses were to change the emphasis to characterization (second-semester sophomores) and processing (first-semester juniors) of materials. Laboratory courses demanded significant time investments by the students and faculty as well as the need to equip and maintain laboratories specific to the materials classifications. Additionally, while introductory courses existed in each of these materials categories, the laboratories were not tied directly to the core course materials. This fact allowed for a change to the laboratory courses without significant impact on the content or quality of the lecture courses.

Incorporated into each of these courses – before and after the curriculum change -- was a strong communications component. The assignments were developed with the goal of teaching students to provide succinct, well-written evidence of their laboratory work through memos and progress reports. Assignments were graded by both the technical and the communications instructors, providing an assessment of the writing quality as well as technical content.

In addition to a change in the curriculum was a change in instructors for these labs. The processing lab was assigned to a new faculty member in fall 2007, and the characterization lab to a new instructor in spring 2008. The communications instructor remained the same in both instances.

In this paper, a comparison will be made between the course as it existed before and after the curriculum change.

Objectives

The primary objective of this course restructure is to broaden the materials processing experience of materials science and engineering students at Virginia Tech and to better prepare them to design their senior capstone projects. This paper will outline changes made to the processing course and the motivations behind those changes. A detailed discussion of the course structure and assignments will illustrate fundamental differences in the approach as of fall 2008.

Approach and Methodology

In the original physical ceramics laboratory, there were 21 separate learning objectives. It was deemed that this was far too many separately listed objectives for a one-credit course, especially given that many were redundant. The revised list of nine learning objectives as well as examples of activities and assignments associated with each are provided in Table 1.

Table 1: Learning objectives and associated activities and assignments in the re-designed processing laboratory course.

Learning Objective	**Example Activities/Assignments**
Apply selected materials processing techniques to prepare materials and manipulate their structures.	• Five weeks of instruction in processing methods/equipment operation. • Team projects to prepare samples for evaluation • Perform on quizzes/homework related to processing methods
Interpret microstructure and its relationship to processing parameters.	• Evaluate effects of processing methods on resulting structure through various optical microscopy techniques • Work with experienced staff/faculty to understand microstructural features • Incorporate data in reports/final paper

Learn how to select and use analytical instrumentation appropriate to the needs of the process.	• Experimental plan exercises • Show competency prior to use • Justification for selection is expected
Compare and contrast how choice of process and process parameters are influenced by material form.	• Training exercises • Project proposal • Team discussions/experimental plan exercises
Apply safety protocols appropriate to the laboratory environment.	• Attend safety seminar given by Environmental Health and Safety Services at Virginia Tech • Include safe handling plan in proposal • Lab conduct
Maintain an accurate record of laboratory work and data in a lab notebook.	• Lessons on lab notebook format • Random, unannounced graded entries in notebooks
Work effectively in a team on an extended technical project.	• Participation in group activities/attendance • Team reports and manuscript • Planning/division of duties and responsibilities • Respectful conduct • Team contracts
Prepare effective technical progress reports.	• Technical and communications expectations outlined by faculty • Graded reports (by technical and communications faculty)
Synthesize, organize and prepare a summary final report that incorporates the motivation, procedures, results and discussion from the extended (semester-long) laboratory exercise.	• Technical and communications expectations outlined by faculty • Two draft manuscripts are submitted with progress reports during the project exercise; feedback is provided • Final report in the form of a journal manuscript

The course has been taught twice since the course consolidation was put in place by the department's undergraduate curriculum committee. It is anticipated that continuous improvements to the laboratory will be made based on student feedback and on input from faculty advisors of senior capstone teams.

The overall objective of the processing laboratory is to draw a close relationship between processing, structure and properties of materials. This relationship is fundamental to materials science and engineering and the lab is critical to planting this concept firmly in the minds and experience of the undergraduate students. The brief introductory lectures, activities and assessment tools are designed to reinforce the theoretical knowledge, hands-on skills and communications skills necessary to practice materials science and engineering.

The concept of the processing-structure-property relationship is fundamental to the study of materials science and engineering. This relationship is the core of a larger "manufacturing stream" that governs everything from the choice of raw materials to characterization and testing methods to evaluation of final product performance. Figure 1 is just one possible schematic representation of this concept.

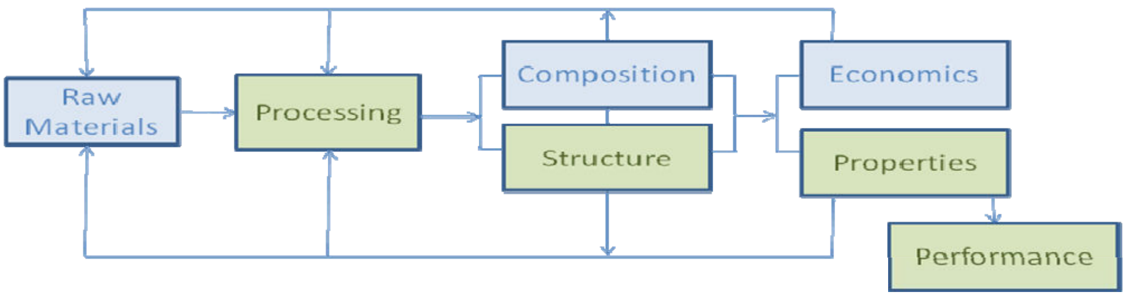

Figure 1: A representation of the critical components in the processing-structure-property relationship common to most materials systems.

Many similarities exist between the ceramic materials lab taught previously and the revised materials processing laboratory. In both cases, the material systems under investigation were and are ceramics and glasses. Fundamental concepts of processing, sample preparation, and characterization and testing remain as the basis for the skills taught in both courses. In both cases, a strong communications component incorporated in each of the assignments was and is a requirement.

<u>Laboratory Activities</u>

Previous Course

In this course which was focused specifically on traditional ceramics processing, the skills taught were specific to a particular technically important product (an industrial insulator for high-power cable), a ceramic whiteware body with a porcelain glaze. The primary processing methods for this course were extrusion, coating and heat treatment. The labs were structured with a one-hour lecture to begin the session, followed by two hours in the lab working on an assigned task related to the semester-long project. Each lab section was divided into two teams and each team was given particular compositions for the body and glaze to manufacture and test. Each of these materials incorporated "designed failures" which the teams were expected to evaluate. They also were to recommend solutions for the problems they encountered. Progress reports and the final report (a maximum of 20 pages plus appendices as needed) were prepared by each student. A format was provided by the instructor. In this laboratory, all of the individual laboratories were laid out with specific tasks for the teams to follow.

Revised Course

One of the primary goals of this revised laboratory is to give students an intuitive understanding of designing experiments in pursuit of a research goal. In accomplishing this goal, it is anticipated that students will be better prepared to take their research to the next level – applying theory to practice.

The first assignment for the course is posted to the website and sent out by e-mail prior to the first class meeting. The students are to bake a cake from scratch and bring it to class with them the first day. In this extra credit assignment, the students (1) perform a visual inspection of the *Surface Morphology/Texture* of the cakes, (2) discuss the use of *Molds and Mold Release Agents* to allow for easy removal of the "samples" from the pans, (3) evaluate *Porosity and Pore Size Distribution* by examining the cross-section of the cakes, and (4) determine the best sampling methods for evaluating *Homogeneity* of each cake using *Density Measurements*. It is through this assignment that the students get their first exposure to the relationship between processing, structure and properties (Figure 2).

Figure 2: First assignment for the class is to bake cakes from scratch and bring them to class for analyses of the processing-structure-property relationship.

This experiment has been very helpful in introducing the basic concepts of materials processing and characterization. The teaching evaluations for the class over the past two years have been full of positive comments from the students about this introductory activity. It has been so well received that it was an invited activity at the 2008 National Educators' Workshop[1] and as a visiting instructor-lead activity for freshmen engineering students at the University of Hartford in November 2008 to introduce them to materials engineering concepts.

Students also are given extra credit for attending a graduate seminar taught by the Virginia Tech Office of Environmental Health and Safety Services. Safety is a major learning objective and is stressed throughout the course and through all of their experiences in the department.

The first seven weeks in the laboratory are spent learning the skills on equipment related to a variety of processing techniques, including slip casting, sol-gel chemistry, glass casting, uniaxial and isostatic pressing, as well as extrusion and heat treatment. The importance of skills, such as calculating batches, mixing, milling, and segregating (sieving) are emphasized early in the semester. Additional skills taught covered those characterization and testing methods not covered in the sophomore lab or those for which the students did not recall in sufficient detail to use in this course. Some of these included Archimedes method and pycnometry for density measurements, Vickers hardness methods, use of the high-powered optical microscope, and sample preparation techniques for mounting/cutting/polishing.

The remaining seven weeks of the semester are spent on an open-ended engineering project intended to illustrate fundamental materials science and engineering concepts. There is no time to evaluate products/applications in detail, as would be done in an engineering design project[2]. In the team projects, groups of three to four students are required to design a research project that illustrates the effects of processing on structure and/or properties of the resultant material. This exercise is one that requires continual redefining. The concept that the initial hypothesis can be changed as the semester moves forward is one that the students find difficult to comprehend. By revising this course to provide an introduction to designing experiments to investigate a problem, it is pushing the students out of their comfort zone and into a realm of uncertainty. They no longer have a recipe for their experiments for which they must prepare an extensive technical report. Instead, they are (1) selecting a problem of interest, (2) proposing a set of experiments that illustrate a specific concept (in this case, the relationship between processing and resulting structure/properties), and (3) learning to document and report on their procedures and results in a technical publication format (i.e. a journal).

In the transition year, student teams drew to determine the "theme" of their projects (i.e. wet forming, dry forming, glass and glass ceramics). However, in the re-designed course, the students were allowed to select any topic that could be accommodated in the lab facilities. While they were pleased to be able to focus on a topic of their choosing, this freedom to choose left them a bit lost. How would they select a theme, let alone a specific topic? To help students better define the research problems they wish to pursue, a brainstorming (also referred to as "brainwriting") session using the 6-3-5 method[3,4] was conducted. The initial reaction of the students was skepticism; however, after going through the exercise, they were much more comfortable with the idea of a team project.

Instead of moving directly from the brainstorming session into the topics, two weeks were devoted to developing the ideas resulting from the session and then to refining the project concepts. The teams each wrote a project proposal for which feedback was provided. They could then further refine their projects outside of class and were able to move directly the next week into experiments. Throughout the semester, the projects were continually altered slightly to accommodate new knowledge. Teams were encouraged to develop process/project flowcharts to assist them in decision making.

<u>Assessment</u>

The grading scheme (Table 2) for the course was established to assess individual skills and knowledge as well as the collaborative efforts of teams. In the original course, most of the grading was based on individual work. However, in addition to the learning objectives for the re-designed course stressing team projects, current engineering practices emphasize the need for graduates to be able to work together to produce bodies of knowledge and to solve industrial problems using a team-based approach. Therefore, the revised grading scheme put more emphasis on teamwork to produce the final product, a technical manuscript. In 2008, 81% of a student's total possible points were based on team scores.

Reconsideration is underway for the course offering in 2009, with an effort to reach a compromise such that individual skills and knowledge will be rewarded as well as the team's performance. The grading scheme will be altered to base final grades on 67% for team performance and 33% for individual performance.

Table 2: Grade structure for MSE 4424 – Materials Laboratory 2 at Virginia Tech.

Task	**Point Value**		
	Prior to Fall 2008	Fall 2008	Fall 2009
Individual			
Quizzes		15	15
Peer Assessment			10
Processing Current Events			5
Progress Reports	26		
Draft Project Report	35		
Final Project Report	15		
Cake (extra credit)		3	3
Lab Safety Seminar (extra credit)		2	2
Team			
Laboratory Notebook	24	15	10
Project Proposal		10	10
Project Presentation			5
Progress Report/Draft Manuscripts		30	20
Final Manuscript		30	25
Total Possible	100	105	105

In the 2008 course, it was intended that the quizzes be based in quantitative calculations that would be straightforward and for which there were clear, easily graded answers. The first quiz was just such a test (batch calculations for glass compositions). However, in an effort to delve deeper into the students' skill sets, the second quiz grade was based on a peer-review exercise. Each student was assigned a proposal made by another team and asked to complete a questionnaire that mimicked a professional review form. They were asked to keep their criticisms constructive and told that they must provide complete evaluations (not "yes-no" answers). Grades for the reviews were based on (1) evidence that they actually read the proposal, (2) consideration of the project proposed sufficient to provide thoughtful evaluations, and (3) depth of the answers to the review questions. They were permitted to simply complete the form or to attach a copy of the proposal with embedded comments to their review form containing short answers. The results were very good and indicated that, in most cases, there was considerable thought given to the reviews.

For the third and final quiz, the students were asked to design two test or quiz questions and keys based on any topic in theoretical or practical processing-structure-property relationships. These questions and answers required that the students could convey more knowledge than simply inserting numbers in an equation and turning the crank. Instead, they had to show sufficient mastery of the topic to design questions and answers that could be considered challenging, yet fair. As an incentive to preparing thought-provoking questions, the best results (those that summarized the topic well and incorporated complete keyed answers) were submitted to the lecture instructor for possible inclusion on the final examination for that class. In this quiz, the students also were given the opportunity to evaluate the contributions of their teammates to their learning experience during the semester. Again, only constructive criticism constituted a high grade.

In assessment, it always is a challenge to determine whether students are meeting the course requirements to achieve a particular grade or if they actually are learning the fundamental concepts that an instructor is attempting to instill in them. It is through the individual assessment that this distinction may be made; however, the indicators may be quite subtle. In 2009, the students will be introduced to the "GOAL" response format, generally associated with the SCALE-UP (Student-Centered Activities for Large Enrollment for Undergraduate Programs) program[5,6]. These designed test responses consist of four parts:

- ✓ **G**ather information (*What are you given and what are you seeking?*),
- ✓ **O**rganize the information (*Identify critical words, variables, etc.*),
- ✓ **A**nalyze (*Perform the calculations or analyses.*), and
- ✓ **L**earn from your efforts (*Why was this problem assigned? What are you learning in this situation?*).

While this format may not be appropriate for all tests, it can provide a clear indication of the level of understanding by the students.

Conclusions

Based on direct feedback from the 2007 and 2008 laboratory students, the revised processing laboratory is working well. Teaching evaluations ranged from 3.2 to 3.9 over the 2 years since the lab consolidation, indicating that the instructor's methods are well-received by the students. In this year's informal discussions with the students (most of which are juniors, but a couple of whom are seniors currently enrolled in the senior capstone projects), the open-ended research projects are of great help in learning to approach a design problem where the solution is not pre-determined. In fact, the seniors expressed some regret that they had not experienced this type of laboratory prior to their year-long senior projects.

While the written component of these projects proved to be labor intensive for the instructors, the obvious increase in quality of the work produced by the students as the semester progressed made the projects a worthwhile time and energy investment. Additionally, according to the student log books, they spent an average of 27 person-hours outside of class on the projects. This amount of voluntary time allowed for some level of confidence on the part of the instructors in the degree of student engagement, especially given that this class was one credit.

There are improvements that can and should be made over the next few years to enhance the impact of the lab; with greater evidence of the benefits of applying theory to practice and the impacts such skills have on successful senior capstone design projects. What data needs to be collected? How long a duration of study is needed? These, and other questions, must be addressed in order to assess and provide verifiable results and guidance to continuous improvement efforts.

All of the specific motivations of the curriculum committee for consolidating the labs from three to two courses are not known. The costs of teaching laboratories and the trends toward decreasing credit hours for graduating from bachelor's degree programs are examples of issues facing many college programs. Although there may have been some hands on experiences lost in the course consolidation process, the gain in the re-design is that students now are not simply performing activities in a lab setting, but are being challenged to work in teams, synthesize data, improve decision making skills and write in a technical manuscript format. All of these activities have been incorporated into the redesigned processing lab with the intention of better preparing the students for their capstone design experience. While assessment methods to determine the impact have not yet been deployed, student feedback is likely to provide a significant contribution to determining the impact of these changes.

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