Integrated Materials Science Lab Experiences in a Mechanical Engineering Curriculum

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Abstract

This paper describes the ongoing efforts to teach materials science in two different courses within a mechanical engineering program at Western Kentucky University. The WKU mechanical engineering curriculum has several components that are integrated experiences over multiple semesters. The objectives for integration of experiences is to provide an alternative to the model where courses are simply information continuums yet are distinct and often not fluid in transition. Integration in the WKU mechanical engineering program also includes an experimental component and a professional component. The courses described here relate primarily to the integrated delivery of the materials engineering topics within the program. However, as a result of the integrated curriculum, the courses also contribute to the experimental and communications aspects of the curriculum.

Mechanical engineering students with diverse academic backgrounds are introduced to the fundamentals of engineering materials in both lecture and laboratory settings as freshman. That lab experience is then complimented in the sophomore year in a lab connected to the course titled mechanics of deformable bodies. This strength of materials lab provides experiences that connect the mechanics concepts being learned with materials property testing. Deliverables from the lab course are established to develop a professional communication style where both theory and experimental analysis are valued highly.

Course objectives and lab experiences in both the freshman and sophomore lab courses are described and presented in the context of the mechanical engineering curriculum. The objective of this paper is to present the courses and to demonstrate the challenges and successes in implementing the integrated plan. Challenges include delivery to students with limited experimental backgrounds. Successes include improved satisfaction by the students since they actually practice the concepts being taught. Approaches used for continual course improvement are also reviewed.

I. Introduction

The traditional undergraduate mechanical engineering curriculum has a single materials science course integrated into a four-year plan[1]. Such courses are typically intended for sophomore or junior level students who have completed some of the introductory science courses

such as physics and chemistry. Many of the Materials textbooks are designed for a student population with some calculus math skills ready to enter into a study of abstract concepts such as those underlying engineering materials. That materials course may have an associated, required laboratory experience. A challenge is always present regarding student understanding of fundamental concepts such as dislocation movement and strengthening mechanisms. This can partially be addressed by laboratory exposure to metal deformation and its related phenomena, experiences limited or non-existent in engineering students[2]. Some educators have implemented a more interactive style of course delivery to address student engagement[3]. Some programs, including the WKU ME program, utilize a laboratory component to the materials course in an attempt to give some hands-on experience[4].

The traditional undergraduate mechanical engineering curriculum contains a "strength of materials' course as part of a mechanics sequence. This course will typically follow a "statics" course and precede a "mechanical design" course. In this way, an integration of mechanics concepts is attained. Few curricula implement a "strength of materials" laboratory component, and mechanics concepts are learned without connection to the actual parts or materials being dealt with. By having a lab experience it is possible to reinforce the concepts learned in lecture. Moreover, by including some metallurgical concepts in the "strengths" lab, one can begin to tie together concepts learned in prior, traditionally less directly tied, courses. This can help build a bridge of knowledge between courses and aid in providing an integrated educational experience.

New engineering programs at Western Kentucky University (WKU) have recently been implemented that are founded upon a projects-based environment with four-year integrated curricula. The programs in Civil, Electrical, and Mechanical Engineering produced their first cohorts in May 2004. This paper discusses the materials science and strength of materials laboratory sequence of the mechanical engineering program. The objective is to highlight the differences in approaches taken to deliver the educational component while commenting on the current understanding of its effectiveness.

II. Course Structures and Interrelationships

Courses in 2 semesters are used to provide engineering materials laboratory experiences to the mechanical engineering students at WKU. These courses are (a) ME240, Materials and Methods of Manufacturing, (b) ME241, Materials and Methods of Manufacturing Laboratory, (c) EM 302, Mechanics of Deformable Bodies, and (d) ME331, Strength of Materials Laboratory. The courses are paired as lecture/lab with ME 240 and ME 241 being taken concurrently, as are courses EM 302 and ME331. The lecture classes are somewhat typical of those found in an engineering curriculum, while the laboratory courses are considered somewhat unique. We will focus on the laboratory courses.

The ME 331 lab course taken with the materials lecture has as a goal; "to introduce engineering students to the analysis tools needed to characterize some important material properties. To give experimental experiences that demonstrate the relationships between materials processing and properties, and that develop data collection, organization and reporting

	ME 241 Course outcomes
1	Characterize dimensional relationships within crystal structures
2	Describe mechanism for strengthening and annealing of alloys
3	Collect and analyze experimental test data
4	Communicate experimental results through tables, graphs and reports
5	Determine mechanical properties from experimental results
6	Characterize some phase and grain structures in a material
7	Have basic familiarity with several manufacturing processes
8	Identify relationships between shaping processes and material properties

Table 1. Learning outcomes for ME 241.

skills. To give exposure to manufacturing methods through site visits and experiment." The course learning outcomes are shown in Table. 1. These are things students are expected to be capable of doing upon completion of the course.

The learning outcomes are assessed at the end of each course offering using a Peer Review of Course Effectiveness session as described elsewhere[5]. For the past three years, the lab experiences have included; math and geometry tools, Crystal structure models, Cold working and annealing of metals, Hardness testing of materials from different processes, Optical Microscope, Observable material structures, ASTM Standard for Grain size analysis, Tensile testing of materials, Joining of rolled stock, Impact testing of alloys, Site Visits. The site visits are an important component through which the manufacturing aspect of the course is delivered.

The ME 331 lab course taken with the "strengths" lecture has as a goal; "to equip students with fundamental principles and techniques for testing and understanding the response of mechanical components to external forces. Develop an understanding of how property data is generated and reported." The course learning outcomes are shown in Table. 2. These are things students are expected to be capable of doing upon completion of the course.

	ME 331 Course outcomes
1	Plan, conduct, analyze and evaluate basic experiments
2	Determine mechanical properties using standard test methods
3	Measure influence of work hardening and/or heat treatment of alloys
4	Measure material response by strain gauge technology
5	Measure structural deflections
6	Compare analytical and theoretical results
7	Communicate test results through reports or presentation

Table 2. Learning outcomes for ME 331.

For the past three years, the ME 331 lab experiences have included; Tensile testing, Rockwell Hardness; Microhardness, Impact testing, Torsion testing, Flexure testing, Heat treatment (HT) strengthening of steel, Tensile and hardness test of HT steel, Metallography of HT steel, Strain Gauge technology, Eccentric loading, Beam stresses and deflections, Compressive load/buckling testing, and a Design Project. These experiences make use of test equipment dedicated to the instruction of undergraduate engineering students. Students perform most tests themselves, after appropriate training on equipment use. This is largely different than the experience found in ME 241 where much of the testing is performed for the students. Thus, the ME 331 lab course allows students to become familiar with the test method as well as the usefulness of the data generated. This is always conducted with a mechanics theme, thereby connecting back to the lecture course.

There is some overlap in the lab experiences the ME students obtain. For example, tensile testing is covered in both lab courses. This is found acceptable for two basic reasons. First, the second exposure is given after a firm foundation of the laws of mechanics is established and students are thus more capable of understanding the terminology and concepts related to the testing. Additionally, there is a greater emphasis on proper experimental method in the second exposure. The second reason is based upon the fact that the course is also required of students pursuing a Civil Engineering degree at WKU. Those students do not have exposure to the tensile testing prior to ME 331. While this provide some discrepancy in student preparation, little difference in performance has been witnessed between the sets of students other than perhaps less reluctance on the part of the ME student to create a report on the topic.

The fact that CE students participate in the lab gives greater incentive to cover some fundamental metallurgical concepts in the "strengths" lab course. Those students do not get exposed to materials science or metallurgy in the present curriculum. Thus, they leave the course with some appreciation of the differences between alloys and the influences of simple processes such as cold working and heat treating of alloys.

III. Integration within the Curriculum

The Materials and Methods of Manufacturing course is the first in the mechanical systems sequence of the mechanical engineering program and is available to first-semester freshman. It is directly built upon at the sophomore level in the ME 331 laboratory course. The second course in the mechanical systems sequence is Statics (EM 221), which is followed by EM 302. The junior level course that builds upon those is ME 344, Mechanical Design. The final course that builds upon the materials laboratory experience is Senior Lab, ME 430. This Capstone laboratory course contains multiple week experimentation projects that student perform as a small team. Typically 2 or 3 of those experiences contain an engineering materials science theme.

Students can gain additional exposure to engineering materials science through a technical elective in the junior or senior years. Processing and Selection of Materials, ME 450, is an upper level elective that goes deeper into the science of materials including exposure to physical metallurgy. The course also gives students experience in the selection process and further depth into process-property-performance relationships. In the future, as the programs

grow, a course in Materials Failure Analysis and Characterization will be developed. This will allow a mechanical engineering student to form some specialization in their coursework.

The deliverables for the ME 241 and ME 331 courses are constructed with the intention of providing students the opportunity to develop a professional communication style. This is built upon in later courses where projects are sufficiently complex and professional-quality reports are expected. Those design courses are a major contributor to the Professional Skills Plans developed by the Faculty in support of the ABET assessment process.

The deliverables for the ME 241 and ME 331 courses are also constructed with the intention of providing experimentation experiences for students early in the curriculum. This is then built upon by later lab courses culminating in ME 430, Senior ME Lab II. That capstone experimentation course is a major contributor to the Design of Experiments Plan developed by the Faculty in support of the ABET assessment process.

IV. Challenges and Successes

One of the greatest challenges faced with the engineering students with regard to experimentation is providing them with an appreciation for the value of thinking out an entire plan before beginning the collection of data. That is not unique to the present courses or programs delivered at WKU, but is something that has been considered in the development of the course sequencing. It is envisioned that the introduction of engineering experimentation at the freshman year, and continuing though to the final semester, will aid in developing an appreciation for the need to create an appropriate plan before testing. Ultimately, by the senior year, the student will be able to draw from many of the experiences gained in the engineering science and the design courses in combination with the laboratory courses started in the freshman and sophomore years as described in this paper.

The initial faculty assessment of the effectiveness of the engineering materials laboratory integration has led to some modifications to the course experiences and expectations. The most significant of these is providing more attention in the freshman course on designing an experiment. The activity to help support this is an open-ended design and experimental test project. In that activity, pairs of students are tasked with joining copper stock that has been cold rolled. They choose two from a variety of joining method options and are to form a hypothesis of which approach will produce the best result. They then construct the samples and, in the process, experience or witness poor choices in manufacturing approaches. Samples produced are then pulled apart in tension and results compared to the hypothesis. This experience provides them with an opportunity complete an entire experiment, and to learn from their mistakes. From the perspective of instruction, little guidance is given other than proper use of tools or materials. The students are left to document and analyze their results and, again, learn from the experience through discussion with peers and the instructor. This experience has proven to be very well received by the students and has provided them with the opportunity learn from failures with little risk.

The need for systematic experimentation is reinforced in the ME 331 lab course through some formal instruction and additional project experiences. By this time it is possible to see that

the students begin to make more of an effort in preparing to test a system or design. While still novice in capability, the author has found that this student development is a positive step in preparing them for experimentation in the junior and senior years. It should also be noted that the same instructor has been delivering both courses, and thus is able to provide a certain level of continuity in these engineering lab courses. That can aid in the capability to connect the course experiences, yet may provide some limitations with regard to approach taught. This possible disadvantage can be counteracted by courses later in the curriculum.

A success in the delivery of ME 241 has been use of a systematic record of lab efforts in a dedicated notebook. Students are provided a notebook at the first meeting and given a set of guidelines for documenting their efforts. While many students resist this activity, it pushes them to pay attention to details and thorough documentation of the testing performed. This is intended to help instill a systematic approach to their efforts that should, in the ideal, translate into placing more effort in the planning stage of the test/experiment. It clearly has had the affect of setting a different, more reasoned, pace to the student activity.

V. Conclusion

The mechanical engineering program at WKU is utilizing two engineering materials lab courses in the freshman and sophomore years that contain a certain level of integration. This is done in the context of a projects-based curriculum that has several tracts that are integrated though plans established by the faculty. The results from reviewing the first offerings of the courses have been presented and do suggest that the approach is effective at engaging students in the experimentation and in connecting academic concepts between two different courses. Ongoing efforts to improve student learning and modify the courses and curriculum include activities by the ME faculty that are also associated with the ABET assessment process.

The courses ME 241 and ME 331 are continuing in the curriculum as outlined in this paper. The approach being used has been found to aid in student comprehension of engineering materials topics, particularly where mechanical properties are concerned. The approach is also found to be useful for establishing an expectation of a sound, systematic experimental approach by the students.

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