Session 1526

Capstone Mechanical Engineering Laboratory Uses Racecar

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Abstract
A capstone mechanical engineering laboratory course is being implemented at the University of South Carolina that develops the student's abilities to analyze complex mechanical and thermal systems, to design experiments, and to develop their professional skills. The course is based upon an integrated sequence of laboratory experiments on a Legends-class racecar. This vehicle is chosen as the system of study because it provides opportunities for the students to apply the spectrum of their mechanical engineering knowledge. It's also exciting to the students. As the students progress through the series of experiments, they are increasingly involved in experimental design (selecting sensors, sensor locations and experimental operating conditions). The course culminates in a truly open-ended design of an experiment of their choosing. This course development project is supported by the National Science Foundation's Instrumentation and Laboratory Improvement Program, the NSF's Course, Curriculum and Laboratory Improvement Program, and the University of South Carolina. This paper describes the work in progress.

I. Motivation and Context for this Project

An integral part of the undergraduate mechanical engineering curricula at the University of South Carolina is sequence of four mechanical engineering laboratory courses. The capstone senior laboratory course, *Mechanical Systems Laboratory* is a two-credit hour course that includes one hour of lecture and three hours of lab each week. Laboratories are offered to sections of about eight students. A major function of this course is to illustrate upper-level mechanical engineering topics. Historically, the experiments were selected primarily to do this and, as a result, they were not directly related to one another. As a result, there were a large number of relatively expensive laboratory equipment items to be maintained, which occupied laboratory space, yet were used only once a semester. Because the students went from one unrelated experiment to another throughout the semester, they did not have the opportunity to develop the "system level" perspective necessary to analyze and understand complex thermal and mechanical systems. Further, because the students were required to run a different experiment each week, many of the laboratories were "canned" in that they did not require any design of the experiment.

In 1997 the department began implementing an outcomes-based assessment process in preparation for ABET accreditation under Engineering Criteria 2000. As part of that processes, it was determined that the capstone *Mechanical Systems Laboratory* should support several of the program's outcomes, including:

- The graduates shall have the ability to analyze, design and realize mechanical and thermal systems.

- The graduates shall have the ability to use contemporary computation techniques and tools.
- The graduate shall have competence in design of experiments, experimental practices and data interpretation.
- The graduates shall have the ability to apply statistical methods to analyze and interpret data.
- The graduates shall have the ability to plan, schedule and execute engineering projects.
- The graduates shall have effective oral and written communication skills.
- The graduates shall have an understanding of and the ability to engage in life-long learning.

It was clear that a new approach for the course was required to accomplish the goal of supporting these student outcomes. The approach taken was to select once complex thermal-mechanical system of study. The students then perform an integrated sequence of laboratory experiments with this system. As the students progress through the series of experiments, they are increasingly involved in experimental design (selecting sensors, sensor locations and experimental operating conditions). In this way, the students develop a systems approach to engineering problems, the ability to design and conduct experiments, and further develop their professional skills.

II. Systems Approach to Engineering Problems

Constructivist learning theory asserts that knowledge is not simply transmitted from teacher to student, but is actively constructed by the mind of the learner through experiences (Piaget, 1973; Vygotsky, 1978). Founded in developmental psychology, constructivism suggests: (a) the learner should be an active organism within the environment, not just responding to stimuli, but engaging and seeking to make sense of things; (b) knowledge is best generated internally, not absorbed from an external source; and (c) the motivation for learning should be intrinsic.

To facilitate such learning by discovery, the teacher and instructional environment must allow repeated, prolonged experiences with the materials and events associated with the topic to be learned. Therefore, students in the *Mechanical Systems Laboratory* course perform a sequence of experiments on one complex system, investigating it in detail. The selected system must provide opportunities for the students to apply the spectrum of their mechanical engineering knowledge, including the principles of mechanics, dynamics, thermodynamics, and heat transfer.

An automobile is the ideal system for this laboratory for several reasons:

- It is compact, yet it incorporates such a variety of subsystems that it involves almost all of the fundamental principles of mechanical engineering;
- For all its complexity, it is a relatively inexpensive system for study; and
- It is in the realm of experience of all students, so they can easily relate to system performance criteria such as efficiency, handling and other factors affecting vehicle operation. These features make the automobile a powerful learning vehicle.

The automobile selected for study in this laboratory course is the Legends car shown in Figure 1. The Inter-Collegiate Association for Racing (ICAR), an academic motor sport involving engineering colleges throughout the country, currently races these 5/8-scale replica vehicles. There are primarily two reasons to use the Legends car:

- There is tremendous enthusiasm among our students for the ICAR sport. The students get excited about applying their engineering knowledge and experimenting it. Such enthusiasm can be a tremendous asset to any required course, particularly a laboratory course; and
- The relationship between the *Mechanical Systems Laboratory* course and the ICAR racing team is synergistic. Corporate sponsorship of the ICAR team provides funds that supplement the College's resources for updating the lab equipment, and the course provides an opportunity for all mechanical engineering students to benefit educationally from the ICAR program.

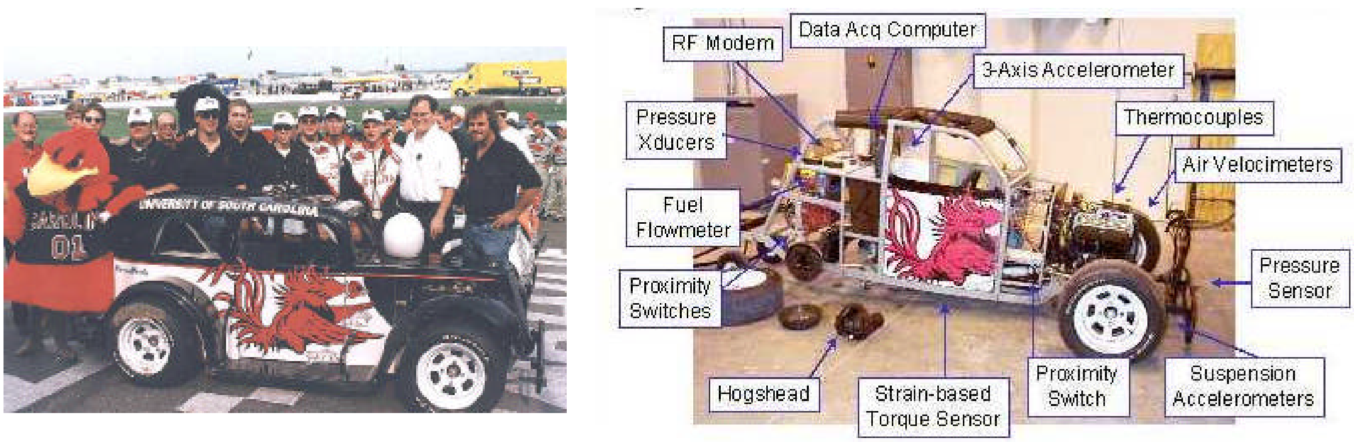

Figure 1. A Legends racecar is used in the Mechanical Systems Laboratory. *Left:* USC's ICAR team formerly raced the lab car. *Right*: The car is accessorized for the instructional laboratory.

An important and relatively unique aspect of the laboratory design is the use of remote wireless telemetry equipment, which allows the entire lab section to control and monitor the experiments while the car is driven. Other equipment procured through the ILI grant has been previously described (Lyons 1999). It should be noted that the instrumentation is of general purpose so the experiments can be modified from semester-to-semester to keep them from getting "stale."

III. Design of Experiments

The engineering education literature describes several methods for students to learn statistical design of experiments (Burke 1993, Ludlow 1995, Abu-Khalaf 1998). Such literature deals with the determination of the smallest number of tests that give the needed answer, factorial design of experiments to determine main effects and interactions, and parametric studies to determine the constitutive behavior of a component or system. The abilities to apply statistics to experimental design and data interpretation are a valuable skill for an engineering graduate.

At USC, the mechanical engineering students develop these abilities in their sophomore and junior laboratory courses and apply them in the capstone laboratory course. Therefore, it was determined that the important skills to develop in the students in the capstone *Mechanical Systems Laboratory* course should be related to the physical design of experiments. In the context used here, physical design of experiments deals with identifying a problem and solving it. It includes the determination test variables and data requirements, the selection of sensors and the design of the instrumentation system.

Physical design of experiments has received very little attention in the engineering literature. Arce (1997) described what was termed a student-designed experiment in an introductory chemistry laboratory. In that experiment, the students were given the necessary equipment and supplies to find out how much heat is needed to melt ice, but were not given a written procedure to follow. Middelberg (1995) discussed a conceptual open-ended experimental design experience performed at the conclusion of a traditional chemical engineering laboratory course. Those students selected a topic from their coursework and then designed an experiment to investigate it. Their design report included background theory, experimental procedures, a budget, a plan for implementation and an examination of safety implications. Middleberg noted the many positive benefits of this experience. However, it was also stated that the students needed more time for consultation with the instructors than was planned, and that they relied too much on the technical staff to select equipment and components.

The approach taken in the *Mechanical Systems Laboratory* course is very similar to that proposed by Middleberg. However, the laboratory experiments and lecture material presented throughout the semester are designed specifically to develop in the students the ability to design experiments. This includes a formalization of the experiment design process, as illustrated in Figure 2.

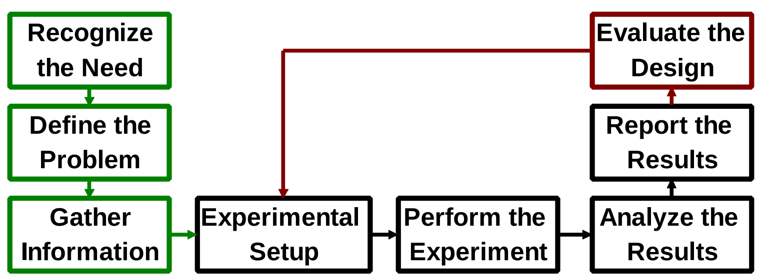

Figure 2. A process model for the physical design of experiments.

There are some very real constraints on implementing the design of experiments process model. An entire semester would be required for a novice to complete the process from need recognition to design evaluation for most laboratory topics appropriate for a capstone course. The laboratory has only one car and set of instrumentation, yet there are four lab sections with 8 students each. It is not feasible for each lab section to set up a different experiment that would last beyond one laboratory period. An additional constraint comes from the mechanical engineering curriculum in that this laboratory must support several other advanced courses in both the thermal-fluid and mechanical systems areas. The bottom line is that it is not possible for the students to completely design and conduct an experiment within 1 semester at the level of complexity required in this course.

To accomplish the objective of developing the ability to confidently design and conduct an experiment, a series of activities are therefore designed that will bring the student through the various learning experiences needed to establish a level of competence in the design of experiments. Educational research refers to this process as scaffolding. Scaffolding allows students to perform tasks that would normally be slightly beyond their ability. The engineering education literature contains descriptions of a number of courses where student knowledge is gained through a scaffolding process (Abbitt, 1996; Byrd, 1995; Chan 1990; Kresta, 1998; Simon 1998). For example, in his paper, 'What We Know About Learning", Simon notes that one of the most powerful ways for learning is for the student to be given worked-out examples, i.e., problem solutions shown worked out step-by-step. This process is akin to learning by doing. As Simon states further, "…you are allowing the student to solve a series of sub-problems, step-by-step." If the sub-problems are designed properly, solution of these sub-problems by the student should culminate in the student being capable of solving the larger problem.

In applying scaffolding to this experiment design process, the "sub-problems" are experiments where the students must incrementally increase their involvement in the design. These laboratory exercises can be thought in terms of the three levels shown in Figure 3. Each level requires progressively higher-order thinking skills. At the beginning of the course, the students complete a Level 1 experiment. This could involve the measurement of temperatures on the engine of the car and assessing the effect of moving air on those temperatures. Through such a simple experiment, the students would become familiar with the data acquisition system and other details associated with the vehicle and instrumentation.

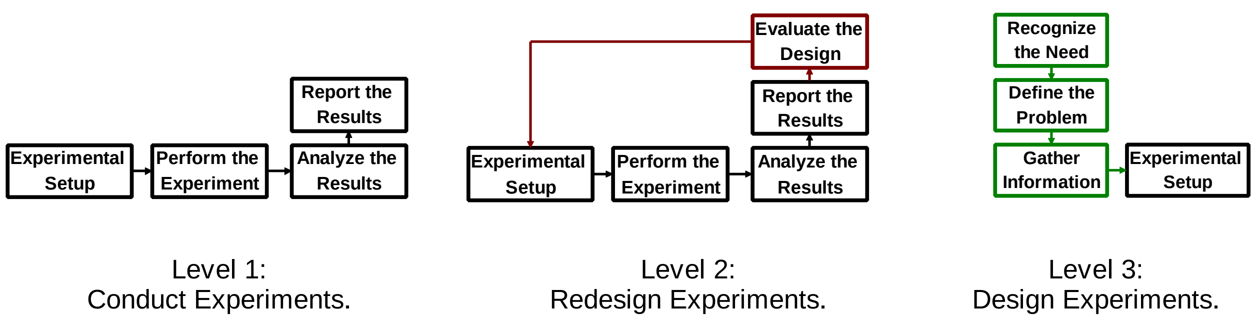

Figure 3. To develop design of experiment abilities, the students complete laboratory projects in levels that required progressively higher-order thinking skills.

The next two experiments during the semester span several weeks each, and give the opportunity for the students to run an experiment, evaluate the results, redesign the experiment and run it again. This is referred to as a Level 2 experiment in Figure 3. For example, accelerometers placed on the rear suspension can investigate the effects of cornering curvature, vehicle speed and road surface bumps on the suspension dynamics. The students complete the experiment using suggested conditions, and as part of their report then evaluate the sensor location, data acquisition parameters (e.g. sampling rate), and physical conditions of the experiment. They would redesign the experiment using their new knowledge in order to improve the results, and then perform it again. The final weeks of the semester are for the students to perform an "open-ended" Level 3 experience that they are required to design and report on both verbally and in writing. The previous labs have to be organized to prepare the students for this "open-ended" lab, where the students will have to be completely familiar with the instrumentation available, the system itself (the race car), and the theory and concepts behind design of engineering experiments. These experiments can naturally vary from semester to semester, and problems identified by the ICAR racing team during practice or competitive events will be one source for ideas for this laboratory module.

III. Concluding Remarks

The revised *Engineering Systems Laboratory* does more than support upper-level mechanical engineering classes. The students will learn to approach and analyze engineering problems from a systems viewpoint, design experiments, apply computer-based instrumentation to study system performance, document their results in writing, and make technical presentations. By using a Legends car as the test system, the course will channel the enthusiasm among our students for the NCAR motor sport into a useful and productive educational experience.

Acknowledgement

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BIOGRAPHICAL INFORMATION

JED LYONS is an Associate Professor of Mechanical Engineering at USC. He teaches engineering materials, manufacturing processes and mechanical design. Recent research areas include high temperature crack growth in superalloys and viscoelastic behavior of thermoplastics. Educational projects include developing mechanical engineering laboratories and leading the NSF Gateway Coalition's Materials Program Area team.

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