How to Teach and Assess Design of Experiments

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Abstract - **The ability to design experiments is a new requirement for engineering graduates introduced by ABET Engineering Criteria 2000 (Criterion 3, Outcome b). This requirement presents new challenges for engineering educators and students alike. The challenge for educators lies in the fact that traditional laboratory experiences typically include well-structured experiments that leave little room for design. Hence, there is a need to re-design at least some of these experiences, to make them more open-ended. The challenge for students lies in the fact that they are used to "cookbook" experiments, hence they find open-ended laboratories difficult. The Inquiry Continuum will be used as a tool to define the process and the skills necessary for the design of engineering experiments. Workshop participants will have an opportunity to apply this process in one of their laboratory courses. Results from the successful implementation of such a process in a variety of engineering disciplines will also be presented. The workshop format will combine direct instruction, individual practice, interaction among the participants, and discussion.**

Index Terms - ABET, accreditation, assessment, design of experiments, program outcomes.

BACKGROUND

The US Accreditation Board for Engineering and Technology (ABET) recently put a new spin on experimentation skills in engineering education. Specifically, Outcome 3b of Engineering Criteria 2000 [1] states that engineering graduates must have "an ability to design and conduct experiments, as well as to analyze and interpret data". While the ability to conduct experiments, as well as the ability to analyze and interpret data has been addressed in traditional laboratory courses, the ability to design experiments presents a new challenge for engineering educators and students alike. Traditional laboratory experiences typically include well-structured experiments, which leave little room for experimental design. Hence, there is a need to re-design at least some of these experiences, to make them more open-ended. On the other hand, students are used to "cookbook" experiments and find open-ended laboratories difficult. Faculty and students need a fairly general process that they can follow to design an experiment for any purpose, much like the general process used for the design of an engineering product.

The inquiry continuum, adapted from reference [2] and shown in Table I, will be used as a tool to understand the process and the skills needed to design an engineering experiment. As we move from the left end of the continuum (demonstration / cookbook lab) towards the right (student-directed / student-designed inquiry), the responsibility for the various tasks outlined on the left column, gradually shifts from the professor to the student. This is a very important observation because research has shown that taking responsibility for one's own learning is one of eight conditions that must be satisfied in order to master a task or subject matter [3]. It is also a necessary condition for the development of students as lifelong learners. Hence, it must be understood that without an opportunity to take responsibility for the decisions about the various tasks of an experiment, students cannot master the process of experimental design.

Workshop participants will first define such a process and then apply it in one of their laboratory courses. Results from the successful implementation of such a process in a variety of engineering courses will also be presented [4 – 5]. The workshop format will combine direct instruction, individual practice, interaction among the participants, and discussion.

WORKSHOP OBJECTIVES

The objectives of the workshop are to:

1. Present the Inquiry Continuum as the framework for the design of engineering laboratory experiences, to help engineering educators select an appropriate level of inquiry for each of their laboratory exercises.
2. Develop a process for the design of engineering experiments, to help students cope with the open-ended nature of student-directed and student-designed inquiries.
3. Offer workshop participants an opportunity to re-evaluate a laboratory from a course of their choice by selecting an appropriate level of student inquiry and following a well-defined process to design an experiment.

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4. Develop guidelines as well as a rubric for assessing student skills in the area of experimental design.

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TABLE I
INQUIRY CONTINUUM

	Lecture / Demo	Cookbook Lab	Structured Lab	Challenge Lab	Student-Directed Inquiry	Student-Designed Inquiry
	Professor is doing science; students watch	Students confirm known result	Professor sets one procedure; students reach own conclusion based on evidence.	Professor poses the problem; students design / test solutions.	Professor selects topic; students pose questions.	Students select topic, identify problems, formulate questions, design & carry out experiments.
Scientific / Engineering Concept	Professor	Professor	Professor	Professor	Professor / Student	Student
Questions Posed	Professor	Professor	Professor	Professor	Professor / Student	Student
Equipment / Materials	Professor	Professor	Professor	Professor / Student	Student	Student
Design of Procedure	Professor	Professor	Professor	Professor / Student	Student	Student
Analysis of Results	Professor	Professor	Professor / Student	Student	Student	Student
Conclusions	Professor	Professor	Professor / Student	Student	Student	Student
Student Skills	Collect information.	Follow directions. Use lab equipment. Collect data.	Make inferences, draw conclusions from one set of data. Replicate results, (variability of results).	Design & test analytical & experimental solutions. Evaluate how well the design solves the problem. Confidence to put forth ideas. Draw conclusions from a range of results.	Pose the right questions. Develop own procedures.	Complete experimental design.
Cons	Little critical thinking. Concepts & processes not internalized.	Outcome is known. Does not model true scientific process.	Students are not involved in experimental design.	Students do not pose the questions.	Takes more time. Increased materials / equipment needs.	Takes more professor time to guide each student or team. Increased materials / equipment needs.