2006-1192: QUALITATIVE, QUANTITATIVE, OPEN-ENDED: A PROGRESSION IN LABORATORY/LECTURE LEARNING

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A Progression in Laboratory/Lecture Learning

Purpose:
This paper describes the teaching of engineering concepts using a three-step progression in learning. The goal is to build students' intuition and confidence in tackling the types of open-ended problems they will encounter when they graduate.

Introduction

The valuable engineer is one who can "figure out" a difficult, open-ended problem. There are a number of quantitative skills that are involved in solving these types of problems which any credible engineer should posses. An outstanding engineer, however, couples intuition and experience with their technical skills. Rephrased, students are not engineers because they can solve problems in a book. They become engineers through the experience of solving open-ended problems. The traditional engineering education, however, places an enormous amount of emphasis on quantitative skills and little emphasis on intuition and solving real problems. Practicing the design process is often left to the senior design process or upper level electives.

This paper outlines a three-step progression in learning that can be implemented early in the engineering curriculum. Each step in the progression focuses on specific skills necessary to be a good engineer. The first experience is a hands-on lab that encourages experimentation without the expectation of numerical results. These laboratory experiences are used to motivate technical lectures. The second experience is the traditional technical lab, focusing on results. The third experience is a student-driven, open-ended design lab. Thus far, this three-step progression has been used in Bucknell University's Introduction to Engineering (First Year level) and Fundamentals of Biomedical Engineering courses (Sophomore level) and will be used in a circuits course and a signals and systems course (both Junior level) during the spring 2006 semester.

Qualitative

Many students enter college with deep-rooted misconceptions. These misconceptions can often lead to poor intuition and difficulty identifying problems. The qualitative lab is designed to directly confront misconceptions and allow free exploration. For example, to demonstrate the concept of skin resistance I asked my students put a 9V battery on their arm and tongue and then explain the difference. To my surprise (and theirs once they put the battery on their tongue) only a handful of student had ever tried this. The purposes of beginning a new section with a qualitative lab are:

1) Students have an opportunity to experiment with physical models.
2) There is an active event that signals to the students that a new section has begun.
3) The relevance of the subject matter can be reinforced so students become invested in the lectures. The data they collect often provides useful examples for class.

4) Students have the opportunity to become comfortable using new equipment or techniques without worrying about results.
5) Students learn not to blindly trust their first assumptions. Misconceptions can be directly confronted.
6) The instructor can gage students' existing knowledge of a subject and focus the follow-up lectures and labs to the appropriate topics and level of difficulty.

The qualitative labs should be graded lightly (check plus, check, check minus) so students do not feel pressure to produce results. At the same time, students must be invested in the lab time. It has been found useful to guide these exploratory experiments with a series of basic questions. For example, "Explain what happens when you touch the battery to your tongue?" "Why do you think your arm and tongue react differently?" "How might you test your hypothesis?" The qualitative lab can be replaced with a demonstration if equipment or time is lacking.

Quantitative

The quantitative labs are, and should be, the core of the traditional engineering education. Without quantitative labs, students will not be competent or credible. For this reason, the quantitative lab is similar to the traditional lab. A few difference exist:

1) Students begin quantitative labs with a more intuitive feel for the material.
2) Students have had exposure to the relevant equipment and can focus on the technical content.
3) Students should collect their own data. In the case of Biomedical Engineering labs, students are more motivated when they collect signals from their own body.
4) It is helpful for groups to compare their results after then turn in their reports. Trends in the data can lead to class discussions.
5) The lab write-up should include a preliminary design for the open-ended lab.

These labs require students to tie the lab exercises back to the theory and calculations from lecture. Quantitative labs are also an opportunity for students to confront the many forms of experimental error and statistical analyses as well as gain an appreciation for what can be completed in the allotted lab time. Grading for the quantitative lab can be the same as for a traditional lab. The preliminary design helps students think beyond the surface level of following a precise lab protocol.

Open-Ended

An ABET requirement is that all engineers experience a senior capstone experience. The final lab in the sequence serves a similar purpose as the senior design but on a smaller time scale.

1) It is important for students to design and conduct their own experiment.
2) Some students will confront failure. It is important in these instances to remind students that technical failures are often successful learning experiences.
3) Students become more independent.

4) Students learn to debug a system.

These labs should be fun while building on technical skills. Grading should be based more on the process followed rather than the results produced. Focusing on the process encourages students to be creative and take measured risks without worrying about the impact on their grade. If time permits, the open-ended lab results can be presented to the class or be used to drive further discussion of advanced topics.

<u>Example Lab Sequence</u>

A number of lab sequences have been designed for the Introduction to Engineering and Fundamentals of Biomedical Engineering courses. Below is an example sequence from the Fundaments course: The relationship between electrical activity and mechanical forces produced by muscles.

The first lab was an introduction to recording the Electromyogram (EMG). Each student recorded an EMG from their calves as they walked, ran, skipped and hopped. They were given the freedom to experiment with other types of walking or jumping. Lab questions focused on correlating mechanical phenomena (force produced by their calves) to electrical phenomena (recorded EMG). The raw data and answers to questions were used to motivate class discussions on basic muscle physiology, electrical activity (action potentials), force production, and the computation of forces and moments in the body.

Armed with theory and technical skills, the second lab focused on recording electrical activity of the bicep when various weights were held out from the body at a 90 degree angle. Students made measurements of their forearm dimensions and calculated the theoretical bicep force needed to support 2, 5 and 10 pound weights (See Ref 1 page 428 for a free body diagram and representative calculation). The importance of a control experiment (holding the arm unloaded - parallel to the body) was stressed. This exercise had the additional benefit of confronting a misconception – a 10lb weight held in the hand required approximately 100lb of force from the bicep. The end result was as plot of the calculated muscular force versus the RMS power of the EMG signal. Again, an opportunity arose to teach an important concept – the single resultant plot was much more informative than turning in all of the raw data. The results from this study were surprising for two of the groups. The signal power from the control measurement (arm held parallel to the body) was larger than when the arm was held perpendicular to the body. Students developed two potential hypotheses. Hypothesis one was that the arm normally does not hang perfectly parallel to the body. Since the bicep was being stretched it may be contracting to return the muscle to its normal (bent) state. Hypothesis two was that activity of the tricep (which is slightly flexed) was being detected. Although the correctness of these hypotheses may be questionable, the students were applying information from class and building critical analysis skills. Follow-up lectures focused on sources of error in the measurements, statistical analysis and the EMG as a tool to diagnose neuromuscular pathologies, In the third lab, students were asked to design an experiment that would quantitatively analyze a movement they found interesting. The only instructions were that their study must involve a force balance and the recording of the EMG from a muscle group. Reference 2 is a good resource for force balances. Some examples of student mini-projects were:

1) What are the muscular forces that must be generated when you arm-wrestle?
2) How much force must your claves generate to perform a Pliè?
3) Which muscles fatigue that fastest?

It should be noted that the content of the labs may not always be directly related. In the example above, the EMG was recorded from different muscles in the first, second and possibly third lab. The important component of the progression was that students were strengthening intuition in the first lab, technical skills and in the second lab and design skills in the last lab.

<u>Assessment</u>

The Bucknell BME program does not have multiple sections of lab/lecture classes. For this reason there was no control class. No direct assessment was performed, however, student feedback was received on the end of course evaluations that related directly to the progression. In addition, a number of students offered informal verbal evaluations. Below are challenges and advantages observed by the instructor.

Challenges for the Student:

1) Some students may become frustrated with the idea that there is not always a "right" answer. This is an expected response for first year and sophomore engineering students who are concurrently taking classes that are taught in the traditional way.
2) The open-ended labs may give the false impression that the instructor did not prepare a lab.
3) There may be a tendency for the qualitative and open-ended labs to be viewed as "not real labs" because the traditional lab skills are not as important.
4) The technical aspects of an open-ended project may not be achieved.
5) Students may become too dependent on the instructor to solve their problems.

Challenges for the Instructor:

1) The design of several interrelated labs is more difficult than creating isolated labs.
2) Instructor support is required during the labs.
3) Quantity of information is sacrificed for quality and depth of learning.
4) The Bucknell Biomedical Engineering Program teaches a number of small classes in an integrated lab/lecture format. It is expected to be more challenging to translate this progression to courses with large enrollments and specified lab times.
5) Preparing students to design a project in three weeks is difficult.

Addressing the Challenges:

Although not all of the challenges above can be addressed, there are some general guidelines that were found to be helpful:

1) Letting students know up front what they will be doing, and why, can help them put the approach into perspective. It is important that they understand that experimentation and design is part of the learning experience and part of being an engineer.
2) Assigning separate grades for technical results and process helped students feel more comfortable with falling short on the technical results
3) If time permits, more than one open-ended lab section can allow students to adjust their protocol if necessary. Along these lines, it was helpful to review proposals before the final lab. Groups either without a clear plan or an over-ambitious plan can be identified and encouraged to revise their proposal. For complex designs, the final lab may span multiple weeks. Students may then focus on particular aspects of design in a systematic way.
4) As students become comfortable with the progression, they approach the qualitative and quantitative labs as precursors to their design lab.

Advantages for the Student:

1) Students practice the process of design several times before the senior capstone experience.
2) Phenomena experienced in lab are used to motivate the lectures.
3) The laboratory becomes a place where real experiments are being conducted.
4) Students realize that the topics in class are not isolated. In the example lab sequence above, students experience the connection between bioelectrical and biomechanical events.
5) Students are not afraid to try things that may not work.
6) Students develop trouble-shooting skills.
7) Student Comments:
   "It was fun being able to see the data coming from us, it made it more real"
   "I liked playing around with the lab tools before I had to use them"
   "The last labs were hard but I learned the most from them."
   "I got a better idea of what engineering was all about."

Advantages for the Instructor:

1) Students often do not realize how much work it is to create a robust lab. By experiencing the lab design process first-hand, they gain an appreciation for instructor-created labs.
2) An additional benefit is that students often will spark the creative in the instructor, providing a source for new lab ideas.
3) It is possible to integrate a single module of this progression inside of a traditional class. In this way, instructors can experiment with the progression without redesigning a course.
4) Students understand why statistical analyses are important when you ask them to "prove" their results.

5) The level of resistance decreases with each iteration of the process.
6) Lab reports are more enjoyable to read.

Conclusion

During the last few decades the physics education community has discovered that while their students were excelling on exams, homework and labs, they were leaving courses with the same intuitive misconceptions they entered with[3]. To address this issue, some have restructured the teaching of physics to first focus on qualitative concepts, followed by the traditional quantitative physics. This paper demonstrates one way to adapt this progression to engineering education. As in the physic community, this progression strengthens different skills in each lab; intuition, technical skill and design experience. We believe that introducing open-ended design in the first and second year will prepare students in the short-term for their senior capstone experience, and in the long-term for their career as professional engineers.

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