Lab Lecture experiments as a principle of teaching

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Instructors who teach theory traditionally provide their students with several ways to ensure that they have attained the required new knowledge or skill before being tested on it. Students can ask questions during lectures and office hours, practice exercises in the textbook and do the assigned homework, etc. Thus **the tradition creates several steps of reassurance for the student that the material has been learned *before* grade points are given or deducted for the results of this learning** demonstrated on the exam.

Surprisingly, this tradition is often defied in laboratory teaching. For example, it is not unusual to find a laboratory assignment, in which the beginning students who were just shown an oscilloscope are required to make measurements using this new instrument, with a possibility of losing the points for getting wrong results. The learning suffers when students are unsure whether they are doing the right thing and whether their data make sense. Lack of reassurance leads to unnecessary stress, shifts focus from learning to fear of losing points, and makes laboratory activities less effective than they should be.

With the goal to create an atmosphere of active learning in the lab, I designed and developed so-called Lab Lecture experiments, which help students **<u>separate learning from earning</u>** points and make sure that the newly learned laboratory procedures are correctly performed. During Lab Lecture experiments students learn new skills, perform measurements, and make accurate records of lab results according to step-by-step instructions given in the Lab Book. Only after the students completed the Lab Lecture experiment they begin doing the Lab experiment on the same topic, for which they earn grade points.

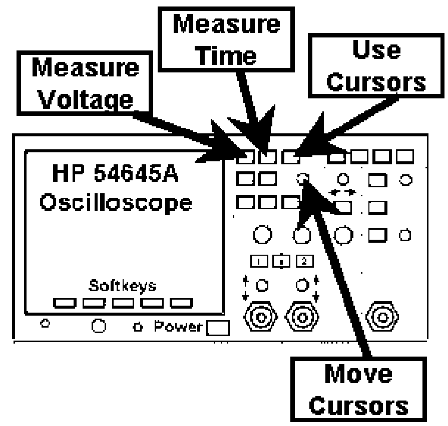
The sequence of Lab Lecture experiments followed by Lab experiments has been successfully used in introductory electric circuit courses at the University of Michigan for three years.

In this paper I explain the structure of Lab Lecture experiments and the role of the Lab instructor, summarize the effectiveness of Lab Lecture experiments implemented in the new Lab Book *Circuits make sense* written for introductory circuit courses, quote the students' comments, and discuss the importance of Lab Lecture experiments with respect to the goals set in ABET 2000 Program Outcomes as well as possible use of this teaching format in other engineering courses.

The structure of a Lab Lecture experiment

Every Lab Lecture experiment is focused on mastery of the equipment and laboratory skills. Since the equipment is unknown to beginning students, all procedures are described in detailed, step-by-step instructions in the Lab Book [1]. The Lab Book explains a particular function of the instrument when this function is needed for a particular measurement.

For example, when students begin to measure the waveforms with the oscilloscope they read explanations of its basic controls accompanied with a sketch that shows where the buttons and knobs are located on the front panel.

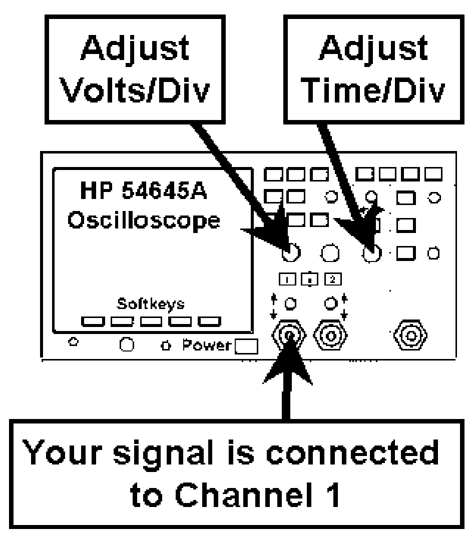


In contrast to traditional lab books, which list *all* controls of an instrument *at the same time* and in fact demand that students memorize them *all at once*, instructions in Lab Lecture experiments [1] are very specific and focused on the particular assignment. **As students perform measurements, they also learn the controls of the instrument step-by-step.**

After the students complete each of their Lab Lecture measurements they have to record their data in the Lab Book [1] using it as a workbook. The Lab Book provides boxes to write numerical results as well as grids to sketch the waveforms or spectra of signals and make plots of experimental data. It also reminds students to make clear records of the units and keep enough significant digits.

One of the key goals of Lab Lecture experiments is to **ensure that *every* measurement makes sense.** Students are encouraged to compare their data with the values expected from theoretical calculations (performed in the pre-lab assignment), with settings of the instrument parameters (does the amplitude measured with the oscilloscope match the amplitude set on the function generator?), with the manufacturer's specifications, etc. The Lab Book provides boxes for writing conclusions on the agreement or disagreement between measured and expected values.

As students continue their work through the Lab Lecture experiments, they read instructions on the following assignment. For example, another sketch in the Lab Book explains how to adjust the Time/Div and Volts/Div, shows the location of the knobs and reminds of the connection of the signal cable.



In each assignment, step-by-step instructions ensure step-by-step learning of new laboratory procedures and instrument functions. **While students work through the Lab Lecture experiments, they develop professional skills of making measurements, recording experimental results and comparing them with theoretical predictions.**

After students completed the Lab Lecture experiment they start working on the *Lab experiment* on the same topic. Lab experiments are more demanding in several respects: instructions are concise, results should be recorded in the lab notebook, and grade points are earned.

Combination of Lab Lecture experiments and Lab experiments ensures the **separation of learning from earning** points. It provides reassurance to students and makes learning in the lab less stressful and much more effective. During Lab Lecture experiments the Lab instructor is involved in ongoing evaluation of student learning, which ensures that the goals of lab teaching are achieved.

The connection between Lab Lecture experiments and other parts of a lab project

The Lab Lecture experiments described here are implemented in teaching EECS 215 "Introduction to circuits" – a 4-credit, one-semester sophomore course required for electrical engineering majors and computer engineering majors at the Department of Electrical Engineering and Computer Science (EECS) at the University of Michigan. Lab sections meet once a week for 3 hours. The lab room has 9 workstations and accommodates up to 18 students (in teams of 2). Over the semester students complete 12 lab reports, including the Lab exam in Lab 5 and the Audio lab in Lab 12, described below. With the exception of Labs 5 and 12, **every 3-hour session includes a combination of *Lab Lecture experiments* and *Lab experiments.***

Every lab project in the course (except Labs 5 and 12) **includes 4 components** linked to each other:

(1) Pre-lab assignment introduces the circuits, which the students will build in the lab, and requires calculations of voltages, currents, etc. The pre-lab accounts for 25% of the grade for every lab report.

(2) Lab Lecture experiments guide students through building the circuits, introduce new experimental skills, explain how to perform measurements, and refer the lab data to the pre-lab calculations to demonstrate the agreement between theory and practice and to assure the students that their work is on the right track and their results make sense. According to the principle of separation of learning from earning, Lab Lecture experiments are not graded.

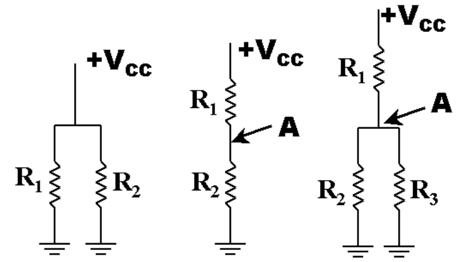
(3) Lab experiments are based on the circuits built in Lab Lecture experiments and the skills learned in Lab Lecture experiments. Lab experiment assignments are succinct, the circuits more sophisticated, the measurements more detailed, and the interaction with the Lab instructor is less frequent. The data obtained in Lab experiments are directly compared with the results of pre-lab calculations, which reassures the students that their experiments are meaningful. The records done in every Lab experiment account for 25% of the grade for the lab report.

(4) Post-lab assignment requires a detailed comparison between experimental data and theoretical predictions, a discussion of their agreement or disagreement, and a presentation of experimental results, which often involves making MATLAB plots. The Post-lab assignment accounts for 50% of the lab grade.

For example, in Lab 1 students begin to learn voltage and current dividers. In the pre-lab they calculate voltages and currents in three simple circuits (see the diagrams on this page) using the nominal resistances and the given power supply voltage V_{CC}. To familiarize students with the color code, the nominal resistances are given as the sets of color bands.

In Lab 1 students learn to use a protoboard, how to measure resistances, voltages, and currents, how to apply voltages from the power supply, etc.

In the *Lab Lecture experiment* students build Circuit 1, apply voltage from the power supply (the same V_{CC}, for which they did the pre-lab calculations) and measure the current through each resistor. The students report their data to the Lab instructor, compare the results of measurements with their own theoretical results obtained in the pre-lab, and discuss the agreement between theory and practice. While students work on their circuits, the Lab instructor checks their pre-lab work (without grading, the instructor certifies that the pre-lab was completed before the lab) and answers student questions on the pre-lab and measurements.



Circuit 1 Circuit 2 Circuit 3

Continuing the *Lab Lecture experiments,* the students build Circuit 2, measure the current and node voltage, report their results to the Lab instructor and repeat the comparison with their pre-lab calculations.

After the students learned how to build circuits and do the measurements in Lab Lecture experiments, after they received guidance from the Lab instructor and asked all questions, they proceed to the Lab experiment. In the *Lab experiment* the students build Circuit 3, measure the currents and voltages, compare the data with their pre-lab calculations and make records in their lab notebook. Every student uses the same notebook for the pre-lab, in-lab, and the post-lab parts of the lab report.

In the post-lab the students repeat the calculations of the voltages and currents in Circuit 3 using the actual resistances measured in the lab, compare the new theoretical results with their own lab data and write a conclusion on the agreement or disagreement between theory and experiments. Students also use their experimental data on Circuit 3 to verify the validity of Kirchhoff's current and voltage laws, and write a comment on the accuracy with which they can verify these laws in the lab.

Thus the structure of every lab reports integrates theoretical and experimental studies, with Lab Lecture experiments playing the crucial role in the middle of the sequence of learning.

The role of Lab instructor in Lab Lecture experiments

Although students perform Lab Lecture experiments according to the Lab Book and work at their own pace, the Lab instructor provides help, advice, and encouragement to all, ensures that everyone learns, and stimulates active learning of the entire group.

At the beginning and at several crucial points during the Lab Lecture the instructor gives an overview and demonstrates the equipment, tools, methods of work, etc. This is an excellent opportunity to explain the meaning and importance of the forthcoming experiments, to focus student attention, to motivate and encourage the whole group.

When students work on Lab Lecture experiments, the Lab instructor circulates the lab to make sure that *all* students successfully perform the assignments and that every student in a team learns the equipment and new skills. Students work in teams of two, and some of them need a reminder to engage *every* student in learning. The instructor also suggests optional assignments to the teams proceeding much faster than the others and offers help to students working much slower than the group. Thus **the Lab instructor ensures active learning and participation of all students.**

When several students start asking similar questions, the Lab instructor may interrupt the work of all students and deliver a mini-lecture to the whole group. For example, I often explain how to record values that do *not* remain "rock-steady" during measurements. Such **advice is most appreciated when many students already see the problem and feel confused:** if given too early (at the very beginning of the Lab Lecture) the advice would be forgotten, if given too late (during the office hours or by e-mail) the opportunity to foster a valuable experimental skill could be lost.

After the students completed a certain measurement, the Lab instructor may ask *all* teams to report their results so that everybody could know what the others observed. For example, in Lab Lecture 1 students read the nominal value of a resistor from its color code and then measure the actual resistance. When all teams report the measured values the instructor summarizes for the whole group whether the color code was read correctly, whether the actual values were indeed within the tolerance range from the nominal, etc. Such summary of *many* experimental results broadens the students' perspective and helps them develop professional intuition.

At the end of the Lab Lecture experiments the Lab instructor summarizes what was learned and explains what lies ahead in the Lab experiment, for which students earn points toward the grade.

The Lab instructor reinforces the self-paced student learning in Lab Lecture experiments with guidance and advice addressed to individual students and to the group as a whole. The Lab instructor reassures students that they are on the right track, reviews their results and discusses whether they make sense, inspects their records of lab data and lets students know whether such records are adequate and acceptable.

Effectiveness of Lab Lecture experiments

As a result of learning during Lab Lectures, the Lab experiments become much less stressful and confusing, much more meaningful, enjoyable, and successful for students. The sequence of Lab Lecture experiments followed by Lab experiments has been used in introductory electric circuit courses EECS 210, 211, and 215 at the University of Michigan for three years.

Most recently, the sequence of Lab Lecture experiments followed by Lab experiments has been implemented in EECS 215 and described in the new Lab Book *Circuits make sense* [1] written for introductory circuit courses and printed by Wiley in 2002. The EECS 215 schedule includes 3 hours of lectures and 3 hours of lab work every week. Since the Lab Book *Circuits make sense* does not have the goal to cover circuit theory, it can be used in parallel with any current textbook on electric circuits.

With the implementation of Lab Lecture experiments, the amount of work that students can accomplish during one semester, in lab sections that meet once a week for 3 hours, is impressive.

The students begin with building voltage dividers and verification of Ohm's law, learn how to use the function generator and oscilloscope, study circuits in the time domain an in the frequency domain, build and test op amp circuits, and eventually assemble three of their amplifiers into an audio system in the Audio Lab (Lab 12). The audio system includes a variable gain amplifier (Lab 6 circuit) for volume control, a variable-response active filter similar to a section of a graphic equalizer (Lab 11 circuit) for tone control, and an audio power amplifier (Lab 7 circuit) as the output stage. In the Audio Lab **every student team builds a working audio system**, verifies that the signals from the function generator fall within the assigned range and are free from clipping, connects the signal from their CD or MP3 player, feeds the output to a speaker, plays their favorite music and demonstrates the volume control and mid-band tone control of their audio system. The Audio Lab crowns the course, brings the feeling of accomplishment and makes the entire course attractive to beginning students.

Successful completion of the intense lab teaching in this course is based on the effectiveness of Lab Lecture experiments and the role they play in student learning the equipment and experimental procedures.

What students think about the Lab Lecture experiments

It is of course important whether the students find the Lab Lecture experiments useful and effective. In several informal questionnaires we encourage students to share their views.

In their answers to the question "Were Lab Lectures necessary? Why?" students wrote:

> "They helped clarify procedure before getting to actual experiments."
>
> "I felt they were especially necessary at the beginning … because there was more to learn about how to do the labs."
>
> "Yes. Made it easier to do the lab."

In their answers to the question "Please comment on the connection between Lab Lectures and Lab experiments" students wrote:

> "I liked the combination. … It was helpful to have the instruction right before doing the experiment."

"[Lab] Lectures served as "training" for experiments."

"Good preparation for experiments."

Lab Lecture experiments meet the goals set in ABET 2000 Program Outcomes

The Lab Lecture experiments described here naturally meet the goals set in the ABET 2000 Program Outcomes, because they provide guidance to students helping them to *develop the ability to conduct experiments as well as to analyze and interpret data*. While students perform Lab Lecture experiments, the instructor is involved in an *ongoing evaluation of student learning,* which ensures that the goals of lab teaching are achieved.

Possible use of Lab Lecture experiments in other engineering courses

In my view, Lab Lecture experiments can be incorporated into many laboratory courses in various engineering disciplines, because they represent a fundamental principle of teaching: students should be free from fear of losing points when they learn new skills, and reassurance from the instructor facilitates their success.

The examples provided in this paper (and many more examples in the Lab Book *Circuits make sense* [1]) might serve as a starting point for development Lab Lecture experiments in other engineering courses.

1. Ganago, A., 2002. *Circuits make sense: A New Lab Book for Introductory Circuit Courses.* Wiley. ISBN 0-471-23547-4

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Alexander O. Ganago received his Ph. D. in Physics and Mathematics from the Moscow State University in Moscow, Russia. As a Senior Scientist at the Biological Research Center of the USSR Academy of Sciences in Pushchino, Russia, he studied molecular mechanisms of the transformation of light energy into the energy of separated electric charges in reaction centers of photosynthetic organisms. He taught laboratory courses at the Pushchino campus of Moscow State University and actively participated in teaching high-school students. In 1990-1996 he worked at Cornell University in Ithaca, NY, studying the dynamics of excited states of molecules with non-linear femtosecond laser spectroscopy at the Chemistry Department and the Division of Plant Biology and teaching several courses at the Chemistry Department and Physics Department. He spent the year of 1997 studying electron transfer rates in photosynthetic reaction centers at the Department of Biochemistry and Molecular Biology of the Pennsylvania State University in University Park, PA. Since 1998 he is working at the University of Michigan in Ann Arbor, MI. As a Senior Engineer and Adjunct Assistant Professor at the Department of Electrical Engineering and Computer Science he is currently teaching introductory laboratory courses in electric circuits.