Modern Electronic Techniques for Physical Measurements:

A proposed upgrade of Lower Division

Laboratories for Physics Majors, University of Oklahoma

1. Introduction.

As part of a general revitalization of the curricula associated with undergraduate majors in the Department of Physics and Astronomy, we propose a project to infuse modern technology into the required Electronics Laboratory Course (E-Lab Course) while integrating teaching techniques to improve student problem solving ability and to increase higher level learning. We envision this project as the first step toward incorporating these ideas and techniques into the entire laboratory portion of the curricula. In particular, we plan to "bootstrap" the improvements in E-Lab to implement improvements in the introductory physics laboratory.

The University of Oklahoma (OU) in general and the Department in particular are quite supportive of innovations in the curriculum, particularly those that involve active learning [Bean 1993] and/or promote critical thinking [Meyers 1986, Fink 1998b]. OU supports the Instructional Development Program that conducts faculty development seminars to help them improve their teaching and assists faculty with course improvement projects such as this one. There are about 100 undergraduate majors in the Department, so it is interested in pedagogy. Thus it invites colloquium speakers at least once a semester to give presentations on the newest ideas and innovations in physics education [Department]. It also provided resources for faculty to attend conferences and workshops on physics education. Finally, it conducts the Physics and Astronomy Informal Seminar on Teaching (PAISOT) for faculty and interested graduate students. About once a month, innovations in teaching methods and materials are discussed in this forum including the integration of Mathematica™ into the curriculum, the use of Web-based materials, and the use of small groups and active learning [Department]. OU has demonstrated its support by providing more than half of the equipment money requested here and other generous support.

We are the appropriate faculty to undertake this project because, for the next few years, we are responsible for the courses that will be directly impacted by this project. JEF will be teaching E-Lab and ERLA will be teaching Introductory Physics for majors, including the introductory physics laboratory. As experimentalists, both JEF and ERLA have considerable experience in computer interfacing and practical electronics. JEF has taught E-Lab previously, 7 years ago, so he is somewhat familiar with the current material and the level of student expertise, and ERLA has taught freshman physics. We are committed to providing our students with the best possible preparation for careers in technology. We feel that appropriate laboratory experiences are vital to this commitment.

Below, we describe the current formulation of the E-Lab Course and briefly present a description of some of the changes that have occurred in electronics that necessitate a modification of the material presented in this course. We then present our goals for the modified E-Lab Course and a brief exposition of our plans to achieve these goals. Finally, our proposed scheme to evaluate the effectiveness of the implemented changes and our ideas for disseminating the results of this project will be presented.

2. The current "Electronics Laboratory for Physics Majors" Course.

In their sophomore year, majors in the Department of Physics and Astronomy take a required Electronics Laboratory Course that consists of 2 coupled 1-semester courses PHY2302 and

PHY2312. Along with our majors, a few students from other departments take this course for a total enrollment of about 30 to 35 students per semester. The purpose of this sequence is to give these students a practical introduction to electronics at a hands-on level. Traditionally, this has been a "cookbook" laboratory that performs a required textbook laboratory each week and an overall individual laboratory project each semester. The introductory physics laboratory is similarly presented currently.

In the last 10 years this course has been somewhat upgraded to include an introduction to data acquisition by computer and the use of microprocessor techniques by using the text, *The Art of Electronics* [Horowitz and Hill 1989], with its associated laboratory manual [Hayes and Horowitz 1991]. There is an emphasis on measurement techniques that do not involve computers, and a focus on the various discrete electronic components and their properties. Whereas there are some computers in the laboratories, they are obsolete Mac II's, and they have not been effectively integrated into the required laboratory exercises or the larger semester projects. Students work in pairs, and everyone works on the same lab exercises each week.

Analog electronics is covered in the first semester (PHY2302) beginning with discrete components, *e.g.* resistors, capacitors, inductors, diodes, transistors, and field-effect transistors (FETs), then continuing with the more integrated components, *e.g.* operational amplifiers (op-amps) and voltage regulators. There is considerable discussion of equivalent circuits and effective models for the various components, but computer aided modeling is not used largely because computers and software were not readily available for this task when this text was produced 10 – 20 years ago. The individual projects are student driven with some guidance by the instructor. Projects are prototyped on breadboards and laboriously hand wired. Designs are largely produced by hand, prototyped, built, and tested, then redesigned, modified, and rebuilt.

The subject of the second semester (PHY2312) is digital electronics. Again small scale integrated circuits, *e.g.* gates, flip-flops, counters, are covered first. Then, the main emphasis of the course is building and programming a simple, relatively outdated, microprocessor-based computer. The assembly techniques are similar to those described above except wire-wrapping is employed. The programming is all performed in assembly language. Some computer interfacing is performed. Analog-digital (A/D) and digital-analog (D/A) conversions are covered. Project organization and execution are similar to PHY2302.

E-Lab, as currently formulated, provides students mainly with descriptive knowledge, *e.g.* electronics terminology, and some protocol knowledge, *e.g.* how to build circuits by hand, how to use various electronics components, and how to find additional circuits/protocols [Fink 1998a, Fink 1999]. Students are not satisfied with the current courses. As expressed in student evaluations, there is essentially uniform dislike for the text, and students do not seem to see much value in the course. Furthermore, faculty who teach the higher level laboratory courses are not satisfied with the electronics background and skills of the students who have completed the current course. Change is warranted.

3. Changes in Electronics.

The technology of designing and building equipment has changed dramatically in the past 20 years. Engineering drawings are now produced via computer aided design (CAD) software, parts are produced with computer aided manufacturing (CAM) techniques, and prototyping is minimized by the use of extensive computer modeling. To accommodate this continuing fast pace of change, we feel that the E-Lab course needs to emphasize critical thinking [Meyers 1986, Paul 1993], problem solving [Heller *et al.* 1992, Heller and Hollabough 1992], and the process of measuring using these modern techniques, rather than the "nuts and bolts" of electronics components [Finley *et al.* 1992].

The rapid pace of development and the demand for reliability have lead to a number of software and hardware tools that have revolutionized electronics. In particular, an electronics industry standard modeling protocol, SPICE [Interactive Image Technologies], has been developed, along with object-oriented data acquisition, data analysis, and experimental control software such as LabVIEW™ from National Instruments [National Instruments]. We feel that it is imperative for our students to benefit from these technological advances and to gain a working introduction to modern electronic techniques. Our students should be introduced to electronic techniques and tools, including instruments, hardware, and software, that serve as a practical introduction to modern electronics and provide a sound basis for the continuing use of the latest technology to create experiments to measure quantities of physical interest.

4. Goals for the redesigned course.

a) An emphasis on learning to measure rather than a series of "cookbook" circuits and techniques.

b) An emphasis on problem solving via electronic measurement and modeling [University of Minnesota].

c) A use of state-of-the-art techniques, *e.g.* virtual instruments (VIs), CAD-CAM circuit boards, programmable VLSI, and computer integration.

d) A better integration with second year courses, *e.g.* waves and optics [Spiegel 1998].

e) A start to the infusion of newer technology into the entire laboratory curriculum.

f) Higher level learning, *i.e.* What is Knowledge? [Fink 1998a, Fink 1998b, Fink 1999]

g) Student skills and knowledge that are transferable to subsequent laboratory courses and future careers.

h) Student confidence and satisfaction.

5. Implementation plans.

The above project goals lead to a series of assessable learning goals with appropriate teaching/learning activities [Angelo and Cross 1993, Fink 1998b]. The assessable goals, assessment tools and teaching/learning activities are given in the table below.

Because electronics technology is progressing and changing so quickly, it is necessary for our students to be able to keep abreast of these developments independent of specific devices and models. This requires a higher level of learning in the Electronics Laboratory [Fink 1998a, Paul 1993]. We feel that it also needs a change in emphasis from specific electronic circuits and devices to hands on measuring. We are, therefore rewriting the laboratories and reorganizing the presentation with the assistance of Prof. Dee Fink, Director of the Instructional Development Program at the University of Oklahoma. Labs will be more exploratory and problem solving in nature with an emphasis on measuring and getting the best possible physical data within the constraints of time and money. We will attempt to produce “contextually-rich” laboratory problems in analogy with the classroom techniques developed by the Physics Education group at the University of Minnesota [University of Minnesota].

Learning Goals	Assessment Strategy	Teaching/Learning Activities

1. Familiarity with Electronic Technology. a) Knows the terminology. b) Can operate tech. effectively. c) Can describe how systems/devices work.	Pencil/paper tests Lab Observation Pencil/paper	Tutorials, readings, use in Labs Lab exercises Lab exercises
2. Use tech to generate Knowledge. a) Use tech to answer questions b) Design technology c) Assess validity of data, tech, info, answer. d) Identify and assess assumptions.	Teacher gives question, Student uses tech to answer Teacher gives question, Student uses tech to answer Teacher gives example of process/results, Student assesses data, tech, info, answer.. Teacher gives example , Student identify/assess assumptions	Practice doing with feedback. Observe others doing Assess own and others' doing, assesses data, tech, info, answer. identify/assess assumptions
3. Progress to answer to "What is Knowledge?" a) Student creates model of knowledge. b) Test complex questions	Create model Use model to answer questions about knowledge.	Reflect Create model Use model to answer questions about knowledge.
4. Consider personal/social value of physics/astronomy. a) Individual nature of scientists. b) Social dimension of work.	Informal discussions in small groups and outside of class	Reflect on the individual and social nature of own small group Read and discuss work of science and scientists
5. Learn how to learn a) How to get info to solve a particular measurement problem. b) What should/can I learn next?	Teacher gives hypothetical situation, Student answers/discusses process to learn info for it.	Use context rich problems Use scientific method and procedures Explore literature/the net/etc.

Because there is considerable software to introduce to the students and because we are contemplating considerable change to the labs, we feel that it is imperative that the course materials be tested and developed with some real students. Thus, we have included 2 undergraduate student assistants and one part time graduate student assistant as developers and test subjects to insure that the resulting laboratories are accessible to students, and that the expected outcomes reflect the real outcomes. We plan to put the course on the Web so the results and materials may be accessible to others within the university and academic community. We employ a similar strategy to improve the undergraduate physics laboratories.

First Semester, PHY2302.

In the first few sessions we will introduce a set of tools that the students can use to explore and to measure electronic parameters. Then they will use these tools to generate knowledge and create additional tools/instruments (See chart above goals 1 & 2). We will use measurements of the characteristics of electronic components and systems as measurement examples. This will re-enforce the learning of the general properties of the electronics. The students will have a comfortable working knowledge of electronics and its capabilities at the end of the course. They will gain some expertise in solving problems of the form “How do I measure X?” (goals 3-5).

A particular example would be a laboratory dealing with operational amplifiers. The previous course gets to op-amps after considering transistors and FETs, and considers them as an extension of these components. Some particular circuits are built and tested and a simple model of the op-amp is developed. In contrast in the new version of the course, we will first consider the ideal op-amp and develop some intuition for its behavior via Electronics Workbench. We will then build some circuits, based on designs derived from the modeling, and measure their actual behavior using LabVIEW™. This behavior will then be compared to the ideal behavior and used to develop a more sophisticated model. The lab will be formulated around amplifying a signal to make it discernable, assessable, and thus useful for building knowledge.

Second Semester, PHY2312.

In the area of digital circuit design and practice, there has been even a greater revolution. In current electronic practice, complex circuits with many relatively simple chips are rarely built, even for one-of-a-kind purposes. Instead, special purpose circuits are produced via programmable logic devices of varying complexity. The resulting designs are then produced as custom chips or are "burned" into an alterable chip. A design only contains logical connections between inputs and outputs. Systems for producing designs for such a paradigm are available and in fact generally free to academic institutions. The production of the final products is also very reasonable because the companies are very interested in generating relationships with universities. One of the leading companies, Vantis [Vantis] an offshoot of Advanced Micro-Devices, has provided free software and special manufacturing offers to us for this purpose. We will therefore alter the teaching of digital electronics to emphasize the use of the simplest components to get an understanding of the properties of digital components. Beyond this we will focus on the design chips for more complex functions via state-of-the-art CAM-CAD software and special purpose programmable VLSI chips. The digital project will involve the design and production of a special purpose interface using these VLSI chips for a measurement or laboratory for introductory physics.

Laboratory and Project Paradigm

The traditional paradigm for designing electronics, especially for physicists who are not experts at this task, is to find a "cookbook" design that approximately meets the desired application and then build it as a prototype on a breadboard with hand-soldered wires for connections. Then the design is tested and modified until it is "good enough" or time has expired. Final products from such a process tend to be unreliable because they include many hand-soldered joints, and they do not incorporate the latest electronic components because cookbooks take time to be published and probably have been in the library for a number of years. This is the approach that is used for student learning and projects in PHY2302/2312. The more modern approach, which is much more cost effective and produces more effective and more reliable circuits, is to use some sort of electronics design and modeling software such as Electronics Workbench™ from Interactive Image Technologies, Ltd. With such a system, one may still begin with “cookbook” designs but they will probably be from a database of designs or from manufacturers “application notes” available on the Web. The designs are then modeled using the industry standard modeling engine SPICE. The effects of parameter and component changes including “worst-case" scenarios can then be modeled. As a result of these tests the design can be modified to be more robust and effective. The newest components can be incorporated because SPICE models for components are routinely provided on the Web by manufacturers. Such models are easily incorporated into Electronics Workbench™. Finally, because the model has been optimized through modeling, it is cost effective to transfer the design to a PC board for the production of even a single circuit. This is time effective also because Electronics Workbench™ has a PC board Layout utility that will automatically generate the appropriate artwork for the production of the circuit. The output of this utility is the appropriate files that a company can use to produce the desired PC board. Our electronics technician in the Department has found that special rates from such companies are available to academic institutions especially for classroom use. We therefore plan to use such facilities to produce professional, robust projects for the students. This has a number of benefits. The students produce a project is professionally produced. They experience the process in a way that is much closer to actual practice than previously. Finally, because the results of the projects will be considerably more robust, they will continue to have an impact on the Department and other students.

For example a possible laboratory project would be to instrument and interface an air track. The project would involve not only creating the appropriate software (virtual instrument VI) for LabVIEW™, but also producing and testing a hardware interface for the A/D and/or D/A card to get signals which could be used to measure velocity and acceleration. Finally further VIs would be produced to analyze the resulting data. The final product would be material, that with small modification, will be incorporated into the updated introductory physics laboratory.

Last year, we were in charge of the freshman physics course, which includes a lab. The computer integration into the experiments for this course is very primitive. It is planned that projects from the E-Lab course will concentrate on being upgrades to the electronic infrastructure for the freshman laboratory experiments. This benefits the Department as a value-added activity. The students in the freshman lab benefit as being end users of the projects from E-Lab, e.g. they will receive an introduction to LabVIEW™. It particularly benefits the students in E-Lab due to the direct applicability of the project, simulating real product oriented production. It also enhances their learning processes by integrating their new skills in electronics with the experimental methods and physics originally presented in the introductory physics course including the laboratory. As these projects are successful, this approach will be extended to projects beyond the introductory physics laboratory for physics majors. Such extensions include other physics laboratory courses, both for majors and for the general student population, demonstrations for various physics courses, including those within the Department and as an outreach to pre-college courses, and Society for Physics Students projects, such as instrumentation for the radio-telescope project currently underway here at the University of

Oklahoma. This project will also be relevant to the physics community. The procedures and results of the E-Lab projects will be presented in an appropriate forum, probably on the Web site dedicated to the project.

6. Assessment plan.

We will conduct the standard formative and summative assessment procedures for the new electronics laboratory [Bloom, et al. 1971; Angelo and Cross, 1993). However, since we are proposing substantial changes to the laboratory portion of our curriculum, we also need to consider a comparative assessment between the previous way of teaching this course and the new way. We discuss each of these three aspects of assessment below.

Formative Assessment: In this portion of the assessment, we will essentially address the question of whether the course "is tracking" the way it should. To do this, we will collect information at multiple times throughout the course. This information will be about the course materials, the course exercises, the students' reactions to the various learning activities, and the teacher's reaction to teaching the lab this new way. One source of feedback will be the advanced students who will be involved in developing and testing the materials to be used in the course. We will periodically ask them what they think about the new materials. Second, we will collect information from the enrolled students. Here we will use mid-course questionnaires, a Web-based bulletin board, and periodic short written feedback answering questions like "What one thing did you learn this past week?" and "What one thing are you confused about?". Finally, we will collect information from the teachers, regarding the time and effort involved in implementing these changes; this is important information for the decision of whether to continue the innovation or, for others elsewhere, whether to consider adapting it.

Summative Assessment: The summative assessment activity is aimed at determining whether the students have achieved the stated learning goals for the course. In the process of designing this course in a new form, we deliberately formulated learning goals in terms that were assessable, and then identified the specific assessment procedures appropriate for each goal. These assessment procedures were presented in the middle column of the table above. Because the learning goals include but go well beyond basic "understand and remember" knowledge goals, the assessment procedures involve many different procedures, more than paper/pencil tests. Here the students will have the chance to really produce something useful and meaningful that will be a true test of their grasp, not only of the particular facts and concepts of electronics but also of the use of electronics to measure physically meaningful quantities. Furthermore, it will demonstrate their ability to generate a protocol to perform a particular set of measurements and to extrapolate the use of data to gain knowledge. Our paradigm for this whole process is basically the “context-rich problem solving” paradigm developed for the teaching of introductory physics at the University of Minnesota. For E-Lab, the practice problem sessions will roughly correspond to weekly laboratories, and testing sessions will correspond to the semester projects.

Comparative Assessment: The reason for conducting comparative assessment is to determine whether this way of teaching the electronics laboratory is n fact better than the previous way of teaching it. "Better" in this case means a great percentage of students had the skills and motevations to generate knowledge by measuring physical quantities using electronics technology, in subsequent courses and in their careers. There are two challenges to this comparative assessment effort: strategic and tactical. The strategic challenge is that the two versions of the course had different goals. However, the two sets of goals are in fact partially overlapping. Both courses include some basic knowledge goals, but the proposed version of the course includes goals that go well beyond the goals of the previous version. Therefore the comparative assessment will need to include both sets of goals, and then note how well the students from each did on the common goals and the goals that were distinct to each version. The second challenge to comparative assessment is tactical: the students from the previous version of the course are not the ones who will be taking the course in the future. However, these students are still available in the department and will be in the second year of the physics sequence of courses. Therefore, they are available for further assessment. We will use this resource to evaluate the effectiveness of both the goals of the previous E-Lab presentation and the version developed in this project. To accomplish this a questionnaire will be developed during the first year of the project and administered to students enrolled in third and fourth year laboratory courses. Faculty, who supervise third and fourth year laboratories, will be questioned about their perception of students' ability to perform measurement tasks using electronics technology. The appropriate questionnaires will be developed in collaboration with Instructional Development Program at OU.

We feel that we have developed a viable and comprehensive assessment plan, which is an integral part of the proposed project to infuse technology and higher level learning into the undergraduate physics program starting with E-Lab.

7. Dissemination plan.

We plan to disseminate extensively the course materials produced by this project and the results of the assessment of the effectiveness of our work. First, and most obviously, we will produce a Web site which features this project. We will particularly attempt to make this Web site accessible by having pointers to it in appropriate places such as NSF, the companies whose software and hardware we are using in the course, and other physics education and laboratory instruction Web sites. Both National Instruments and Interactive Image Technologies have active programs to incorporate and adapt their software for educational purposes. We will cooperate fully with them to license and to distribute materials that result from this project.

For the broader audience interested in science and mathematics education, locally we will make presentations to PISOT and Instructional Development Seminars so that our results will be useful within the Department and elsewhere at OU. We are cooperating with Prof. Dee Fink to publish the results of the project in the appropriate education literature and to present the results at the appropriate conferences. Possible target journals for such publications are *College Teaching*, *The Physics Teacher*, *American Journal of Physics, Physics Education*, and *The Journal of College Science Teaching.* Finally, we will cooperate with other colleges and universities to transfer and adapt our innovative materials to their needs. To this end there has been interest expressed in this project at Bowdoin College, and we are contacting our colleagues at Southern Nazarene University who are at the forefront of programs to improve the physics curriculum.

8. Conclusion.

Here we propose an ambitious undertaking, not only to upgrade the computer and instrumentation facilities of PHY2302/2312, Electronics Laboratory for Physics Majors, but also to alter the organization, emphasis, and presentation of the course to reflect modern electronics technology and practice. We feel that as a result of this project, our students will benefit greatly. In particular, we feel that they will be more competitive in the workplace and that they will be able to produce more meaningful and rewarding advanced laboratory projects.

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Vantis Corporation http://www.vantis.com