# Redesign of the Introduction to Modern Physics Course: Second Phase

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Last summer, we (Philip Kromer, Dr. Roger Bengtson, and Dr. Ken Gentle) began a redesign of the Introduction to Modern Physics laboratory class at UT-Austin. The impetus for this work was a grant from the Hewlett Foundation to add a group project to the course, and an offer from National Instruments of free software, discounted hardware, and engineering assistance. We were able to enumerate our goals for the course, and made many additions to its curriculum. We added a significant group project in which students explore an advanced subject and learn to prepare technical papers as a team. We acquired three computers and instrumented several labs for data acquisition in LabView. We also made significant improvements in the lab facilities and equipment. Both the students' and the instructors' comments indicate these changes were successful.

Several important steps remain, however. We must rewrite the course lab manual to reflect the new experiments and course structure. We would like the lab manual to reflect computer data analysis and data acquisition methods, and we would like to prepare an introductory module on these topics. Several experiments need improvement. The bulk of this work will be to implement data acquisition on pre-existing experiments (we would like to instrument six more experiments this summer). We have two interesting projects underway which we would like to complete, a PC-based lock-in and the pendulum interface, described below. These are novel and general applications of LabView in a teaching laboratory and we plan to share our results with the LabView community.

We would also like to document the results of this project. We will publish the lab manual on-line -- this lets us modify lab procedure during the semester, and will provide a resource to instructors of similar courses. We would like to prepare papers on some of our experiments for a teaching journal and for the National Instruments newsletter. We would like to document the LabView code we have written and make it available on-line. Finally, we would like to report on the redesign itself and share the lessons we have learned.

### *Lab Manual and Other Resources*

The old lab manual has several good features, but its experiment descriptions were out of date even before we added DAQ and redesigned the course. At this point, no single experiment is up to date. We would like to revise the old manual to include the new experiments and expectations.

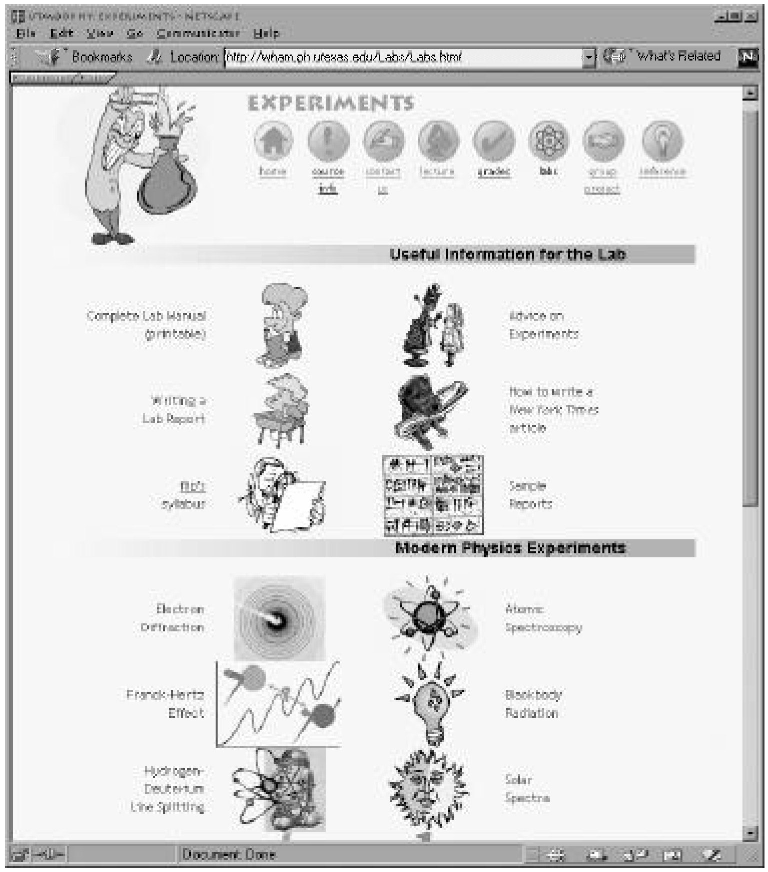
The old manual gave only a general overview of each experiment, and the student was expected to find details of the experiment and analysis in the references (usually teaching journal articles). This is, generally, a good thing: they will certainly have to consult the references to carry out their analysis, and that preparation should start as early as possible. However, we found that many students did not understand the motivation or context of their experiments. So one goal of the new lab manual will be to ensure that each student understands exactly why each phenomenon is important, why it is interesting, and to include references with historical information (including original papers and Nobel lectures). Another goal is to allow more room for open-ended experimentation – to give advanced students the freedom to play but to still keep the problem well defined.

We have required the students do their data analysis by computer for some time, and our progress with data acquisition in LabView is detailed below. Proficiency with LabView or Mathematica makes a student quite attractive to most research groups, and students seem excited by the opportunity to learn these tools. We would like to include, in the lab manual, a gentle introduction to data acquisition in LabView and to data analysis in Excel and Mathematica.

We will distribute the manual via the course web page – we will no longer hand out a hardcopy, although we will make a printable version available. The electronic form will allow us to make changes, during the semester, as we wish to clear up points and as the students uncover new phenomena or references.

We would like the web page to be useful to other members of the physics and the LabView communities. The manual and the Mathematica / LabView introductions will be available on-line (during our redesign, we found other schools' lab manuals quite useful). We will document and package the VI's for each experiment and make them publicly available. The web page has a preliminary references page, containing links to vendors and physics web sites. We would like to expand this section, and to publicize our site as a resource on other physics pages.

The six introductory labs have been available on-line for two semesters; a snapshot of the web page appears at right. Student responses for this preliminary section of the manual have been quite positive.




Modern Physics web page: on-line lab manual.
http://wham.ph.utexas.edu/Labs/Labs.html

### *Interesting Project #1: Lapdog (LabView Analysis of Pendulum Devices and Other Grooviness)*

Last year we acquired a chaotic dynamics experiment – a driven, damped pendulum – which has become one of the most popular experiments in the lab. The device is quite straightforward, and its evolution is given by a simple, one-line differential equation: yet it demonstrates a remarkable range of dynamical behavior and allows students to explore fundamental topics in nonlinear dynamics. The device is driven by a standalone circuit, and its position and velocity are determined with a quadrature encoder. The pendulum comes with a dedicated interface board and an extremely basic DOS program to record data. The program does not have great performance, can only log small data sets, can only generate phase portraits and Poincaré sections, and has a rather Baroque interface. It does not allow us to zoom in on specific regions of phase space, and all calibration calculations must be done off-line.

Jeff Sherman, an undergraduate student, is working to implement the pendulum interface in LabView. Students in our lab and the senior lab will be able to discover many features of dynamical systems in a very visual, physical way. Our goal is not simply to re-implement the old software but to build a flexible platform with which we can explore this remarkable device. The program uses an E-series DAQ board and two external circuits (a rotary encoder interface and a timer circuit to generate the pulse train). Daedalon, the company who makes this device, has expressed interest in acquiring the program.

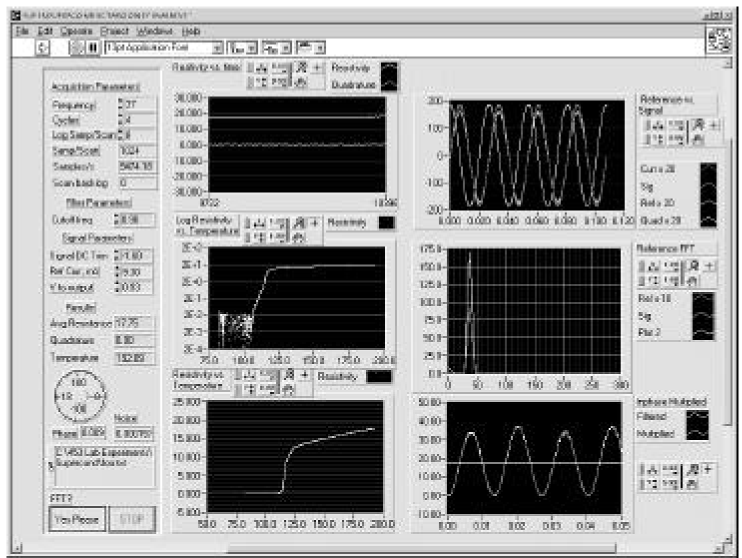
We would like to work this summer to complete the basic interface, and to replace the driver circuit in LabView. This will allow us to automate mapping of the parameter space – a rewarding but tedious process. Even more exciting is the opportunity to implement closed-loop control of a chaotic system, a current research topic. We plan to prepare papers for the *American Journal of Physics* and for the National Instruments *Instrumentation Newsletter* describing the results.

### *Interesting Project #2: Lock-in detection*

Lock-in detection is a technique for measuring a very small signal against broadband noise several times larger than the signal itself. Lock-in amplifiers are widely used in research laboratories and are an important experimental tool. Commercial lock-in amplifiers start at $3000 for analog units and can cost up to $7500 for high-end digital units. We have implemented a digital lock-in detector in LabView using only an E-series DAQ board and a homemade amplifier. The program consists of a main program and four sub-VIs, each a screen in size. It acquires, plots, and logs data in real-time and is reasonably responsive (on a Pentium-II 233).

We can perform many very sensitive measurements, using only general-purpose equipment, by this technique. We currently use the program to watch the resistance of a high-$T_c$ superconductor as it undergoes the superconducting transition. Our current version can measure down to 500 nV, or 50 $\mu\Omega$ at 10 mA -- a drop of 3 to 4 orders in magnitude from the resistance in the normal state. The quality of the input amplifier currently limits the sensitivity – a better amplifier could quite possibly extend this value another order of magnitude. This approaches the quality of commercial devices and greatly exceeds the sensitivity of anything else in our lab.

One project for the summer is to adapt the lock-in program to allow a careful determination of the hall voltage in a semiconductor sample. For the specimens and magnetic fields available to us, the deflection is a few hundred microvolts full scale (on top of a much larger signal), which is near our limit for a reliable DC measurement. Among several other improvements to this experiment, we would like to use the lock-in program to measure the hall voltage.



Our lock-in detection VI

There are many other applications for a lock-in detector at the junior or senior lab level. Preston and Dietz list the photoelectric effect, modulation spectroscopy, and the Franck-Hertz effect as potential applications, and the EG&G *Lock in Applications Anthology* gives 20 more experiments. In addition to its significant versatility in an advanced lab, this tool is a good introduction to the use of a lock-in. Since the visual layout of a LabView program directly reflects its schematic conception, it is easy to see how the signal proceeds through the major blocks of the lock-in. The data acquisition segments are small and easily abstracted, allowing us to acquaint the students with only the functional components. We can also display, visually, the signal at many points in the data path – being able to call up a real time power spectrum of the signal as it proceeds through the device is a big win! We can also use LabView to *simulate* the lock-in, and, in fact, we will have students complete a LabView lock-in simulation as a pre-lab preparation. That is, we can not only put a lock-in on every PC in our lab, but we can give each student one to take home!

We need to work over the summer to improve and quantify the performance of our program, and adapt it to the Hall effect experiment. We plan to write up the results in the *American Journal of Physics*. We also want to make the VI's and documentation available on our web page, for instructors (or researchers!) to adapt.

### *Experiments to Improve*

While those applications of LabView are quite fun, the most important value of adopting PC data acquisition in our course has been to several of the basic labs. Several of our labs require the student to generate current-voltage graphs for a given system, but for several experiments the tedium of data collection obscures the elegant and important physics.

For example, we have a lab to demonstrate the photoelectric effect that requires the student to gather a V-I curve for the photocell, for each of five wavelengths. Each V-I curve requires about one hundred data points and so the lab usually ends up taking 12 hours (over two weeks), in the dark, looking at a noisy readout on a nanoammeter. Furthermore, only one feature of each graph is used – the value of the stopping potential – and so all that work ends up producing just five data points! With a quick and dirty LabView program we wrote this semester, students were able to generate several copies of each graph, for six wavelengths, in *one* lab period. No value is lost – the data analysis is still quite subtle -- but students are now able to concentrate on the important, fundamental physics rather than the mind-numbing data collection.

Students who complete these labs early in the semester will use a working LabView program. However, those who wish to gain experience programming LabView will be given only a template VI and guidance in completing the program. We have found that a good number of students express interest (and succeed!) in learning LabView. For some other labs, the student completes a simulation of the experiment in LabView before coming to class. This gives both LabView experience and a sense for what happens in the lab.

**Which Modern Physics experiments have a significant data acquisition component?**

| | Student writes part of the program: | Student is given a working program: | Instrumented, but not with LabView: | Not yet, but perhaps in the future: | No data acquisition needed: |
|---|---|---|---|---|---|
| Electron Diffraction | | | | | **8** |
| Atomic Spectra | | | | | **8** |
| Hydrogen-Deuterium Splitting | | | | **8** | |
| Photoelectric Effect | **4** | **4** | | | |
| Light Emitting Diodes | **4** | **4** | | | |
| Blackbody Radiation | **4** | | | | |
| Speed of Light | **4** | **4** | | | |
| Franck-Hertz Effect | | | **4** | | |
| Ramsauer-Townsend | **4** (simulation) | **4** | | | |
| Electron Spin Resonance | | **4** | | | |
| Superconductivity | **4** (simulation) | **4** | | | |
| X-Ray Diffraction | | | | | **8** |
| Nuclear Spectroscopy | | | **4** | | |
| Relativity | | | **4** | | |
| Solar Spectra | | | | **8** | |
| Chaos | | **4** | | | |
| Lasers | | | | | **8** |
| Semiconductors | | **4** | | | |

### *Budget*

We would like to request funding for an assistant researcher's part-time salary through June, July and August. The total cost is $3,834.

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|---|---|---|
| Salary (per month) | | $ 1,278.00 |
| Months | × | 3 |
| Total Grant Required | | $ 3,834.00 |

## *Conclusions*

Funding for one graduate student (Philip Kromer) for the summer will allow us to

- Rewrite the lab manual.
- Write an on-line introduction to data acquisition in LabView and to data analysis in Mathematica and Excel.
- Present papers on several experiments in academic teaching journals.
- Document the work we have done and make it available, through the course web page, to the physics and LabView community.
- Improve several experiments, including LabView implementation.
- Continue work on the non-linear pendulum and the LabView-based lock-in amplifier.

We feel that these projects will not only benefit the future students but will also produce significant ancillary benefits for the physics and LabView communities.