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Is There a Future for the Advanced Lab?

by Jonathan F. Reichert

Have we created a kind of myth that a multi-topic advanced laboratory experience is no longer a meaningful bridge between introductory physics laboratories and experimental physics research? How tempting it is to engage our students in “real” research projects even in their junior year, to have them experience discovery, get their names on publications, and even have a chance at national recognition from the APS. Everybody wins! Or do they?

When are most students really ready to begin doing research? When do they have the level of theoretical and experimental expertise for the experience to benefit both parties? How about freshman year? I had such a student, who worked in my research lab for all four years and then went to the Princeton Gravity Group to become the principal design engineer of WMAP, the microwave background detector that changed our understanding of the universe. But we do not design and build undergraduate experimental physics programs only for the superstars of this world, just as it would not make sense to create a theoretical curriculum for the Feynmans and Einsteins that so rarely come along.

For most students, three or four years of laboratory instruction, with increasingly sophisticated experiments, is a far better preparation. The advanced laboratory is the essential bridge between highly scripted exercises demonstrating a phenomenon and the independence of an actual research setting. It is a bridge that offers exposure to a breadth of topics and a wide variety of techniques, as well as reasonable ownership of the experiments themselves. For many students, it is the seminal experience in which they discover their future research interest. And the expertise gained in the advanced laboratory is a gift they bring to any research or industrial lab.

This article is hardly the first call for more attention to be paid to advanced laboratory instruction. Dick Peterson wrote an inspiring piece¹ in the March/April 2007 issue of *Interactions*. “Lighting the Fire,” drawn from his many years of experience in running such a program at Bethel College, describing just why it is “crucial to bring the advanced physics lab in from the cold.” Harvey Leff, in his 2007 AAPT President’s Commentary, both laid out the case for advanced lab support and discussed some of the efforts that had already been initiated. They included the Advanced Lab Listserv, <http://lists.aapt.org/avlab>, the newly formed professional organization, ALPhA (Advanced Laboratory Physics Association) and the NSF-sponsored Topical Conference at Michigan in 2009. In addition, with NSF support, ALPhA has launched a highly successful series of Immersions where faculty members “immerse” themselves in one advanced laboratory apparatus for three days in order to become confident enough to teach that experiment in their home institutions. The aim of all these efforts has been to create a community of faculty committed to advanced laboratory instruction that will not only continue to support existing programs but will also bring new experiments, new insights and new ways to evaluate and improve the advanced lab.

But others envision a different approach to advanced lab instruction. *APS News* published a [Viewpoint in its February 2007](#) issue suggesting the replacement of the hands-on equipment laboratory with well-designed



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computer simulations.² “It’s hard to imagine that significant damage would be done to the training of future generations of physics majors if most of their undergraduate laboratories were replaced by well-designed simulations on the computer,” claims the author, relying on a study by Finkelstein et al.³ that looked at large-scale introductory labs using simple dc circuits with batteries and bulbs. According to the results of the study, students using the simulations both performed better on physics concepts and developed greater facility at manipulating real components. The Viewpoint goes on to discuss the use of flight simulators to teach pilots how to fly particular aircraft.

But maybe a few sentences in the conclusion of Finkelstein et al.’s argument were overlooked. “We do not suggest that simulations necessarily promote conceptual learning nor do they ensure facility with real equipment,” the conclusion states. “Computers are far from the magic bullet many people look for in education.” Do you want to fly on a plane whose crew only learned on a computer simulator? I’ll wait for the next flight.

Computer simulation can be a wonderful aid for students, particularly in understanding the basic principles behind complicated experiments. Not only simulations but analogs can be of considerable help in introducing new abstract concepts with concrete examples. These aids can certainly enhance the educational experience for the student, but they are no replacement for the “real deal”. One can study simulation of nuclear spins in a magnetic field and observe a precessing sphere, but students still need to put their own samples in a real pulsed NMR spectrometer and attempt to measure spin-spin and spin-lattice relaxation times as well as chemical shift and other NMR parameters.

At some time an experimental physicist should build a real circuit, trouble-shoot it, find the bad connections, the wrong connections, the bad components, the noisy power supply, the ground loops, the mismatched impedances, the wrong optical reflection, the misaligned crystal, the vibrating table, the 60 Hz pickup, the realities of experimental physics. This takes time, patience, skill, experience, and cultivated intuition based on fundamental physics principles. These skills are essential to experimental physics. This lack of hands-on preparation with real apparatus is already problematic in graduate research programs.⁴

A fair question to ask is whether it is the best use of our time and talent to develop the sophisticated and stable software that would be needed to replace advanced lab apparatus. I would argue that the time and talent would be better directed at developing new experiments and new apparatus. When I attend the APS March Meeting with its eight or nine thousand papers, I always wonder if there isn’t at least the germ of an idea for a new advanced lab experiment in the research being presented. Among the ten thousand scientists, is anyone asking that question? Has anyone asked for NSF support to build an experiment or supply the necessary samples to study a new solid state effect? Has anyone thought about modifications that might make a research experiment robust and student-accessible?

Attending APS meetings with the express intent of finding new experiments for the advanced lab would be a perfect project for ALPhA. I even have a name for these volunteers, α -Miners. After all, they will be digging for the ‘gold’ of experimental physics; new, up-to-date, exciting experiments that can be adapted for the advanced lab. But, we need more than a few dedicated ALPhA members. We need the entire experimental community to, at a minimum, be on the look-out for new instructional experiments related to their own research. And, if there are, even if it is just ‘maybe’, they have a responsibility to let the physics community know. They need not take the responsibility for building the experiment, but they can put a suggestion on the listserv, publish an article in AJP, contact ALPhA or even inform one of the several companies that build advanced lab experiments.

What should an advanced laboratory look like? Having visited labs, seen equipment, talked to faculty, and even looked at student reports, I am personally aware of many outstanding programs. But no document better expresses the course goals than the one written for the University of Michigan’s Physics 441/442.

This course is a hands-on survey of the experimental foundations of modern physics. Some of the goals of this course are:

- 1) *To allow you to reproduce and understand the experimental results that are the underpinnings of modern physics.*
- 2) *To provide you with an opportunity to develop critical writing skills and understand how to effectively present your scientific work to a larger audience.*
- 3) *To familiarize you with experimental techniques employed in contemporary research and industrial laboratories.*
- 4) *To give you a survey, via experiment, of many of the sub-fields of modern physics, and the pertinent experimental issues in each.*
- 5) *To expose you to the realities of the laboratory experience, where things don’t always work, where the issues are*

not always clear, and where progress depends on perseverance, ingenuity, and judgment.

6) To learn and appreciate the ethical and social issues that are involved in scientific research. These include the handling of proprietary information, respect for colleagues and adherence to high standards of honesty in reporting scientific results.

You should be prepared for a fundamental difference in difficulty and philosophy between this course and preceding physics labs. This is going to be a “problem solving” experience, as distinct from a “cook-book” laboratory. You may have to teach yourself how to use and calibrate many different kinds of test equipment. You may have to search for weak signals in the presence of noise. You may have to use statistical techniques to extract results from ambiguous data sets. Your success with the experiments, and with the course, will depend on the dedication and initiative that you apply to solving whatever puzzles arise. This is simply part of the reality and joy of the experimental method.

How do we go about evaluating an advanced laboratory program? Student popularity should not be a criterion, but evaluation by students several years afterwards, when they are working in industry or doing graduate research would be extremely useful. Feedback from industrial employers would also be important. Bob Fenstermacher, at Drew University, described the many letters he has received from graduates praising their advanced lab even though, at the time they were taking the class, many found it difficult and sometimes frustrating. He also described a young woman so empowered by her success with an optical pumping experiment that she is now studying atomic physics at the University of Virginia with Gordon Cates. Students can be “turned-on” in a well-designed, well-equipped advanced lab, but we need to acquire more than anecdotal data to assure support for these programs.

But what are the professional rewards or lack of them for faculty who create, improve and sustain these advanced lab programs? Here is an area of teaching where faculty need to spend long hours, have a wide breadth of knowledge, not only of theoretical concepts but of instrumental skills, data analysis, and trouble-shooting. They often have to make electrical and mechanical repairs themselves, build new equipment, and spend long hours tutoring students. These talents and efforts deserve a level of recognition including advancement, tenure, salary increases and collegial recognition that is often sadly lacking.

The APS has always recognized outstanding research and, in particular, through the Apker Awards, honors exceptional research performed by undergraduates. However, the physics community currently does nothing to recognize the altruistic and heroic work done by those who have created outstanding advanced laboratory programs. If we do not acknowledge and honor these exceptional efforts, I fear that our upcoming faculty and staff will be far less likely to develop the skills necessary to run this important program. In a recent faculty search, Drew University was able to identify few candidates among 85 applicants who were both qualified and willing to teach their advanced lab program.

An APS award for creating, developing, and maintaining an outstanding advanced laboratory program should be created. I urge the experimental physics community to let APS know that such a prize or award is long overdue. I am not so naive as to think that this will change the reward structure of academic institutions—but it is at least a first step in that direction. It will emphasize the importance of this essential teaching program. Laboratory exploration is America’s physics heritage; we are the tinkerers, the builders; we have the history of great experimental physics, let’s not lose it. Is there a future for the advanced lab? The answer lies in your hands!

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¹ [Interactions Across Physics and Education](#)

² [Viewpoint: The Virtues of Virtual Experiments](#)

³ Finkelstein, N.D. et al *Phys. Rev ST Phys. Educ. Res.*, 1, 010103 (2005)⁴. Piston, David *Nature* 484, 440-441 (2012)

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