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# The Advanced Lab: Hallmark of an Outstanding Undergraduate Program

Jonathan F. Reichert

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## GUEST EDITORIAL

# The Advanced Lab: Hallmark of an Outstanding Undergraduate Program

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For high school seniors interested in majoring in physics, the number of prestigious schools offering an undergraduate degree can be overwhelming. What schools should they apply to? What factors should the teachers and counselors consider as they evaluate these programs? Many colleges and universities have distinguished reputations, but these reputations are almost always based on their research and graduate programs. Which ones have undergraduate programs that nurture and develop undergraduate students?

If I had to pick a single "test" to judge the excellence of an undergraduate physics major program, it would be the quality of that department's advanced laboratory offerings. I would ask the following questions:

- Does the department have modern physics apparatus? I don't mean computers, which everyone has. I am speaking of equipment to do experiments in modern optics, cosmic rays, atomic physics, magnetism, low temperature, x-rays, solid state, Mössbauer, magnetic resonance, and plasma, as well as modern measuring instrumentations such as fast digital scopes, lock-in amplifiers, multi-channel analyzers, and spectrum analyzers. Simply put, is the experimental program comprehensive in both content and equipment?
- Does the advanced lab program allow students ample time to carry out experiments? The standard should be a minimum of two complete afternoons per week, plus open hours at least several evenings per week, and several weeks to complete each experiment.
- Do the students get to make choices, choose parameters, and make modifications and additions? Is there an open end to most experiments?
- Do the students get their hands on the equipment, put it together, align the optics, trace the signal, and adjust the parameters? Or is everything connected and ready to take the data when they walk in the door?
- Is an advanced lab course required for at least two semesters, preferably three or four?
- Does the equipment work? Is it kept in good condition?
- Are the advanced lab courses taught every semester? Are they taught by the faculty?
- Is there a machine shop available to the students?

Such an advanced laboratory program is expensive in both dollars and in faculty time and effort. But such programs clearly demonstrate the commitment of the faculty to their undergraduate students and their education. This is a real commitment (not just words) because the faculty will likely not receive professional recognition for their hard work. But their students will greatly benefit from this laboratory experience, even if they gripe about how much they have to work during the course.

Why should students want such an advanced lab as a major part of their undergraduate program? Let me list some reasons:

- It will give them a breadth of experience in many areas of experimental physics. Undergraduate years are not the time to specialize; they are a time to explore the various fields of physics.
- It will give them the opportunity to learn important experimental techniques: using a lock-in amplifier, a multichannel analyzer, a spectrum analyzer, coincident pulse counting, and many others too numerous to list.
- It will include "classic" experiments, some of which led to the Nobel Prize. Students will be able to make their own measurements, analyze their own data, and "discover" essential physics for themselves.
- It will teach students the crucial difference between a theoretical prediction and an experimental verification. For example, one can rather quickly explain the Michelson interferometer, but it will likely take a student considerable time and effort to align one, especially to observe white-light fringes.
- It will provide a venue in which to practice technical writing, including organizing data, data interpretation, and clear technical exposition, all of which are essential for students' future endeavors.
- Many advanced lab programs require students to make oral presentations in the style of contributed conference talks. This is a difficult but important task. Where else do they get a chance to learn this skill in an undergraduate program?
- The advanced lab may be the best place to find out if experimental physics is in your future.

Some departments have come up with what they claim is a good reason for seriously limiting, or entirely eliminating a junior/senior advanced lab: "real" research. "Our students go directly into a real research laboratory, some as early as their sophomore year. They get actual research experience, not canned labs." It sounds good: *undergraduate research*—the new buzz words. There is also a prestigious national award, the Apker Prize, for the best research work done by undergraduate students at two types of postsecondary schools. Even a runner-up in this competition is given high-profile national recognition. The research done by Apker recipients is undeniably impressive. But how do we know the value of other undergraduate research experiences? Were they actually appropriate and valuable for those students?

Do departments give the same careful scrutiny to a proposed undergraduate research experience that they give to an advanced lab offerings? Or do they simply let faculty members bring undergraduates into a research lab to do with them what they will? Where is the oversight of this part of the undergraduate program? Who decides the criteria for a

  

quality research experience and if they have been met? Does the research experience provide a broad range of experimental topics? Does it allow the student to configure the apparatus, choose experimental parameters, master the theoretical concepts, learn a variety of experimental skills and techniques, and make independent decisions? Or does the project mostly benefit the faculty by having the student perform routine tasks under the tutelage of a graduate student? How much does the student actually contribute to the project? Of course, no matter what the actual value of the students' work, it still may produce a name on a publication. That looks good on a résumé.

I can personally cite several disastrous experiences I have come across when interviewing rising seniors and newly graduated students for positions here at TeachSpin. These students did undergraduate "research" and had their names on one or more publications yet were clearly cheated by their departments when it came to their experimental physics education. Their projects primarily involved data logging and computer programming, which apparently provided almost no experience with either basic instrumentation or measurement. They had developed few experimental skills and had had little exposure to areas of physics outside their "research."

I am not claiming that a robust advanced lab course will win a popularity contest. Students always seem to underestimate the amount of time and effort it takes to successfully complete an experiment. And even if it is a great experience, it may not be as glamorous as being around any kind of research. But I do not believe that faculty should be trying to please their students or asking students what courses they *want* to take. The right question, which is one the faculty themselves should be answering is "What courses do these students *need* to experience in order to fulfill their long-term goals as physics majors? What courses will help them become the best scientists they can be?"

It seems to me rather strange that the one place in our modern colleges and universities where that mentoring responsibility is taken very seriously is in the athletics department. Coaches are given essentially carte blanche by both the administration and the students themselves to demand anything from the student-athlete: practices six days a week for three or four hours a day; starting in the summer before regular classes; physical workouts that push the boundaries of human endurance. They don't ask the students what they like to do; they tell them what it takes to make the team, what it takes to win! That's what physics faculty should be doing—telling our students what they need to learn to optimize their physics degrees.

## I. REBALANCING

I may be old fashioned (I'm certainly old), but I believe that colleges and universities should still be significantly invested in teaching, at all levels: undergraduate, graduate and postdoctoral. We need to re-establish the balance and take our undergraduate program, with its essential advanced laboratory, seriously. To encourage this rebalance, my wife and I have established and endowed a new American Physical Society (APS) national award for excellence in advanced laboratory instruction. This year, at the APS March Meeting in Denver, the first award will be presented to Gabe Spaulding, of Illinois Wesleyan University, for his advanced lab program. Gabe will give an invited talk at this meeting that I hope to see published in this journal. The entire physics community can then learn about an advanced laboratory that the APS awards committee believes is an outstanding model program for others to emulate.

One other advanced laboratory prize has just been established and will be given jointly by the American Association of Physics Teachers (AAPT) and the Advanced Laboratory Physics Association (ALPhA). This award will be offered annually for a student or team of students that actually builds, operates, and leaves as a legacy an advanced lab experiment as a capstone project. TeachSpin Inc. proposed this award and has guaranteed to fund it for five years. It is an award I strongly support. Building a working advanced laboratory experiment is a monumental task for an undergraduate—one comparable to a research paper. Only truly exceptional students, with real experimental skills, should attempt this, but those who succeed should be considered for national recognition.

## II. DISCLAIMER

This editorial may appear self-serving because I am the president of TeachSpin, Inc., a company that designs and manufactures apparatus primarily for advanced lab instruction. In a way, I suppose, it is self-serving because it was my deep concern for the future of the advanced laboratory aspect of the undergraduate curriculum that led me to create TeachSpin. I've watched schools abandon the advanced lab, or reduce it to a one-semester, two-credit-hour course. I've seen schools cut advanced lab budgets, with the excuse that undergraduate research is preferable. No matter how sincere the intentions, I believe that these changes actually benefit the careers of the faculty, not their students' education. Faculty members do not have to "waste time" learning experimental techniques outside their own area of research. They do not have to find space, maintain apparatus, grade lab reports, design new experiments, or do all the other tasks associated with such a lab. Scarce department resources do not have to be "wasted" on the advanced lab.

Don't misconstrue my message; I am not saying that every department without an advanced laboratory program is giving a poor education to its undergraduates. What I am saying is that a department *with* an outstanding advanced lab is highly likely to provide a stellar undergraduate education. That's the one I would bet on!

Jonathan F. Reichert
*President, TeachSpin Inc. Buffalo, New York*