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Forum on Education

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Chandralekha Singh and Enrique Galvez, Editors

IN THIS ISSUE

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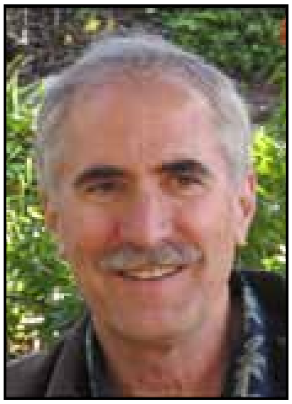
From the Chair

By Larry Woolf



At this time of year, FEd activities are plentiful. Chandralekha Singh, our energetic FEd Chair-Elect is chairing the FEd Program Committee, which is putting together a diverse set of invited sessions for the 2011 March and April Meetings (which this year are, for the most part, actually in March and April). Renee Diehl, FEd Vice-Chair and chair of the Nominating Committee, is working with her team to garner a highly qualified set of candidates for the open FEd Executive Committee positions. For the upcoming election, those positions include Vice-Chair, APS At-Large, APS/AAPT At-Large, and Secretary/Treasurer. You should expect to see a ballot in the near future.

Chandralekha Singh is also co-editor of this newsletter, along with Enrique Galvez. Thanks to both for their efforts in creating this newsletter, which includes many interesting articles on topics from the 2010 Gordon Conference on Physics Research and Education. I'd also like to acknowledge the Teacher Preparation Section editor, John Stewart, as well as Carl Mungan for his Browsing the Journals and Web Watch contributions.

The objective of the Forum on Education is to provide an arena to discuss "the advancement and diffusion of knowledge regarding the inter-relation of physics, physicists and education." In the rest of this article, I'd like to suggest some topics that seem worthy of discussion–and ultimately advancement and diffusion–from my perspective as an industrial physicist for nearly 30 years. These ideas are mine and do not necessarily represent those of the FEd or the APS in any way. Most of these issues have not been generally discussed in the FEd newsletters.

I'd like to discuss my perspective on job skills that are critical for success in industry and the related issues of how we can best prepare physics students for careers in industry, since most physics graduates will not have academic careers. I think useful skills can be broadly classified into 4 areas:

1. Specific deep content knowledge in the core areas of physics
2. Broad awareness of a wide range of topics in physics, other sciences, engineering, manufacturing, quality assurance, intellectual property, and program management
3. Skills for solving both well defined and ill-defined problems, generating new ideas/innovating, experimental design to model and test those ideas, data analysis and documentation, and written and verbal communication, including proposals, papers, and presentations.
4. Ability for lifelong learning. While learning tends to exclusively utilize the professor/student format in classrooms, such a structure is rare after graduation. Students need to be able to transition from a structured classroom learning environment to a non-structured environment.

If these ideas are valid, then how can both graduate and undergraduate physics programs be structured to optimize the preparation of graduates for their future careers? A related topic of how to best prepare K-12 students for their post-high school trajectories led to the development of the Benchmarks for Science Literacy and the National Science Education Standards. Both sets of standards were a consensus, developed and reviewed by experts and stakeholders.

By analogy, should there also be some sort of standards/ learning goals/ guidelines/best practices that assist physics departments in determining what their graduating students should know and be able to do? Would it be best to do this at a national level, to minimize the efforts of resource-limited physics departments and professors? If so, what is the best way to develop these standards? Can they be developed in a scientific manner? Should there also be standards/learning goals for what students should know and be able to do for each physics class?

These types of learning goals are part of at least one science education initiative (Ref. 1), but it is not clear if this initiative has been broadly considered or adopted. In order to generate standards/learning goals that prepare students for future careers, there also must be continuous communication and feedback between those that provide the physics education and those that utilize the results of that education. Is there appropriate communication and feedback between physics departments and those that hire their graduates? If so, how is it being accomplished, what is the impact, and how it is being assessed?

Ensuring that the physics education is relevant and of the highest quality is in the best interest of the student, professor, department, college or university, industry, and ultimately the nation, as our national competitiveness and standard of living result from our ability to lead in innovation and productivity, much of it derived from the work of physicists.

I welcome your thoughts on these issues. Please consider writing a letter to the editor or an article about this topic for the newsletter.

Reference 1: *Learning Goals Resources*, Carl Weiman Science Education Initiative; http://www.cwsei.ubc.ca/resources/learn_goals.htm

Larry Woolf is principal optical scientist and senior program manager at General Atomics, where he has been active in education activities since 1992, mostly focused on K - 12 science.

Fed Sessions at the 2011 March and April APS Meetings

Chandralekha Singh, FEd Program Chair

The Forum on Education program committee and the session organizers have put together an exciting program for the 2011 APS meetings.

March Meeting: March 20-25, Dallas, TX

Invited Sessions sponsored or co-sponsored by the FEd

1. Enhancing graduate education in physics: Focus on skills, organized by Renee Diehl, Penn State University (sponsored by FEd, co-sponsored by FGSA)

2. Educating physicists for industrial careers, organized by Mary Lanzerotti, Pacific Lutheran University (sponsored by FIAP, co-sponsored by FEd)

3. Broader Impact: Partnerships and resources to achieve successful public and K-12 outreach and engagement, organized by Eric Marshall, (sponsored by FEd, co-sponsored by FPS)

4. Mentoring undergraduate research, organized by Sue Coppersmith, University of Wisconsin (sponsored by DCMP, co-sponsored by FEd)

5. Physics Education Research in upper-division physics courses, organized by Paula Heron, University of Washington (sponsored by FEd)

Focus Sessions sponsored or co-sponsored by the FEd

1. New ways of communicating physics, organized by Leonardo Colletti (sponsored by FEd)

2. Teaching computational physics to classroom and research students, organized by Vicky Kalogera, Northwestern University and Amy Bug, Swarthmore College (sponsored by DCOMP, co-sponsored by FEd)

Tutorials and Workshops sponsored or co-sponsored by the FEd

1. Tutorial: Careers in industries and national labs; a Pre-Meeting Tutorial, Organized by Stefan Zollner, (sponsored by the APS Tutorial Program and co-sponsored by FEd).

2. Workshop: Tools and tips for teaching quantum mechanics, a Pre-Meeting Workshop, organized by Chandralekha Singh, (sponsored by FEd)

April Meeting: April 30 – May 3, Anaheim, CA

1. Excellence in physics education award session, organized by Paula Heron (sponsored by FEd)

2. Physics Education Research: Solved problems and open questions, organized by John Thompson (sponsored by FEd jointly with the American Association of Physics Teachers (AAPT))

3. Best practices in undergraduate research experiences, organized by Juan Burciaga (sponsored by FEd jointly with AAPT, co-sponsored by FGSA)

4. Educating and exciting the public about physics, organized by Larry Woolf (sponsored by FEd, co-sponsored by FGSA)

5. Best practices in K-12 physics teacher preparation programs, organized by Alice Churukian (sponsored by FEd)

6. Effective use of technology: engaging students inside and outside classrooms, organized by Homeyra Sadaghiani (sponsored by FEd)

Focus Sessions sponsored or co-sponsored by the FEd

Integrating modern physics into the K-12 curriculum, organized by Peggy Norris (sponsored by FEd, co-sponsored by DNP)

FEd Program Committee for 2011 March and April meetings

Juan Burciaga (Denison University), Alice Churukian (University of North Carolina), Paula Heron (University of Washington), Ruth Howes (Ball State University), Laird Kramer (Florida International University), Eric Marshall, Peggy Norris (Sanford Laboratory), Homeyra Sadaghiani (Pomona College), Amber Stuver (California Institute of Technology-LIGO), John Thompson (University of Maine), Lawrence Woolf (General Atomics), Chandralekha Singh (University of Pittsburgh).

Acknowledgment: The FEd program committee would like to thank Gary White (Director SPS & Sigma Pi Sigma) and Tom Olsen (Assistant Director SPS) for representing the FEd at the March and April 2011 sorters meetings.

Letter to the Editor

in response to an article by Art Hobson in the Summer 2010 Newsletter titled: "A Better Way to Increase Physics Majors: Greater Emphasis on Concepts"

Stewart E. Brekke

I agree with Dr. Hobson that we must also instill the ideas of physics besides teaching primarily mathematical problem solving to high school students. However, a sound basic course in physics problem solving is also necessary. Too often, students are given a course in conceptual physics without the math. For non-science majors in high school, I prefer to also give them the problem solving because they may later change their minds and want to take physics or chemistry in college and find they need a great deal of work and effort to just compete with the other science majors. Too often conceptual physics has meant a non-mathematical course, which deludes the student into thinking physics is all words and interesting experiments and demonstrations. Then the student takes a real college course only to become totally overwhelmed when the mathematics becomes the main part of the college course. We need strong ideas as well as a strong mathematics component in the high school course. I have worked mostly with inner city minority students and have found that with proper preparation and lessons, using drills and practices, and a lot of problem solving help, even the most at-risk students can do a strong mathematical course.

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Alternative Pathways to High School Physics Teaching

Jean P. Krisch

Each year about 200,000 US teachers are certified for K-12 instruction [1]. Most of the teachers come through traditional, institution based teacher training program but approximately 40,000-60,000 teachers are certified though alternate routes [1,2]. Pathways outside of the traditional bachelors programs offer viable teaching opportunities for highly qualified, mid-career professionals with no teacher training. With the growing concern about the very low number of qualified physics teachers in US high schools, the teachers prepared in alternative certification programs in the US are a potential pool of high quality talent. APS and AAPT are working to address the physics teacher shortage through PhysTEC and PTec [3,4], programs that work within the traditional teacher training structure. While this will increase the number of well trained physics teachers coming through institutional programs, it will probably not meet the national need for quality physics instruction. Alternative certification is another route to physics teaching which should not be overlooked. This article provides a very brief overview of alternative certification as a pathway into secondary classrooms and a discussion of some of the questions about alternative certification as a source of teachers.

Alternative certification programs began in the 1980's as a way to meet teacher shortages [5] and have evolved into a significant source of teachers. The National Center for Alternative Certification (http://www.teach-now.org) lists ten different alternative certification routes (http://www.teach-now.org/classes.html). Several of the categories are programs directed at individuals with a bachelor's degree, the pool of interest for potential physics instructors. They provide a search engine where someone interested in becoming a physics teacher can search for training opportunities. For example, selecting D. C. and asking for programs requiring a bachelor's degree brought up the DC Teaching Fellows, a highly selective program aimed at professionals with no teaching background. Going though the web site list, state by state, one finds that many of the listed programs require institutional course work with the state-by-state variation reflecting the primary state control of the teacher certification process. Teacher certification is state regulated and there is a large variation in certification rules. There are national accreditation organizations that are used by some states, the National Council for the Accreditation of Teacher Education (NCATE- http://www.ncate.org) and Teacher Education Accreditation Council (TEAC- http://www.teac.org) but there are no national accreditation standards.

The last listing on the Alternative Certification classification includes programs like Teach for America (http://www.teachforamerica.org) and Troops for Teachers (http://www.proudtoserveagain.com), both possible sources for physics teachers. The American Association of Colleges for Teacher Education http://www.aacte.org/ is also a source of information for program shoppers with the time and financial support to return to school. Online programs may be of particular interest to prospective teachers who must remain employed while re-training. A web search brings up programs like that at Western Governors University (http://www.wgu.edu). This is an NCATE accredited on-line program to prepare physics teachers. It is advertised as a program that "prepares you to teach how the world moves." There are many other on-line programs available. *

Alternative Certification implies that licensure is necessary to teach but an alternative pathway into the classroom is to teach at a private school where certification is not necessarily required. The National Association of Independent Schools (http://www.nais.org/) has an on-line career center for private school job searches and the AAPT Career Center (www.aapt.org) has a physics specific job center.

Alternative routes to the physics classroom are important for individuals who cannot access traditional programs. They are of interest to groups, like APS and AAPT, working to increase the number of US physics teachers because they are a diverse pool of high quality talent. Statistics gathered by the National Center for Educational Information (www.ncei.com) indicate that individuals being certified though participation in alternative programs are often found teaching in high demand areas like math and science [5,6]. The average alternative program participant is more likely to be older, male and more ethnically diverse than a typical teacher certified through a traditional program [5,6] Both the National Education Association [5] and the American Federation of Teachers [7] have endorsed alternative programs, recognizing them as a way of increasing the diversity of the nation's teachers.

One concern about alternative training is the quality of teachers produced by non-traditional routes into the classroom. A recent National Research Council report [2] finds that current research indicates no correlation between the route into teaching and classroom teaching effectiveness. This is not necessarily an equivalence statement. The report points out that current research comparisons may not "capture important differences in teacher preparation" [2], and calls for more comparative studies using factors like content preparation, field experiences, classroom management training, timing of various training components and training links with other university departments. The last factor is of strong interest to physics departments, especially those operating alternative programs like that at SUNY-Buffalo State College [8].

In the past year, two reports about teacher preparation have emphasized problems with US teacher training. The report from the National Research Council, *Preparing Teachers: Building Evidence for Sound Policy* [2], points out the lack of data on the outcomes of different teacher training programs. Closer to home, the Task Force on Teacher Education [9] reports that the preparation of US physics teachers is "largely inefficient, mostly incoherent, and massively unprepared to deal with the current and future needs of the nation's students", the incoherence echoing the NRC report on program variations. Individual physicists, with APS help, can work to improve local physics teacher training within the institutional molds [3]. APS might also influence alternative training by informative outreach at national meetings [10]. While the main interest of physicists is the training of high school physics teachers, in a 2006 policy statement APS has emphasized that "high-quality education is essential for the progress of science and for the public understanding of its importance." Continual advocacy for improved science education, both locally and globally, is crucial [11]. Keeping in contact with the broader developments in general teacher preparation, both traditional and alternative, is also important. Training good teachers of physics and informing teacher training groups about the importance of physics are both necessary to improve physics education in the US.

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*Programs are cited as examples of available programs. The author does not endorse or recommend any specific teacher training program.

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Education-Outreach According to Vanilla Ice: Strategies for High-Quality, Effective Education Efforts

Greta M. Zenner Petersen

“Stop, collaborate and listen.” Although it pains me to say this, Vanilla Ice might have been onto something. Two decades after he released his hit single, “Ice, Ice, Baby”,[1] he is mocked and hardly even considered a B-list celebrity, but in the opening lyrics to his song, he offers valuable advice that we should take seriously when working on education-outreach projects. The process of beginning an education-outreach program or activity can seem daunting–so many possibilities, so many audiences, so many needs–which can leave a person feeling at a loss of where to start. Three imperatives from a forgotten rapper at the end of the last millennium can help.

Stop: Slow Down, Conduct Background Work, and Lay a Foundation

One of my biggest pieces of advice for working on an education-outreach project is to slow down. Frequently, researchers and education professionals alike jump too quickly to the hands-on phase of development, bypassing several important preparatory steps. When included at the beginning of development, these steps will make the entire process go more smoothly and increase the quality of the final product, whether an entire multi-year program, or a single classroom demonstration. The first of these steps is setting goals, and the second is understanding your audience.

Set Goals

Once you have chosen the approximate content area and approach (e.g., hands-on activity, after-school program, kit, teacher training, etc.) for your education-outreach project, it is essential to set goals. These will help you to establish a framework for your evaluation process, to re-focus during the development phase, and to know if you accomplished what you set out to do. If you fail to decide ahead of time what you hope to achieve and what you hope your target audience will gain, it becomes very difficult to know if you actually succeeded.

The most commonly considered category of goals is content learning goals–what content do we want our target audience to learn or master through participating in the education-outreach project? While this category of goals maybe feel simple and clear-cut, it is still essential to enumerate and concretely define them. Leaving content learning goals unspoken and abstract invites confusion and makes it difficult to knowing whether you have achieved them. Do not underestimate the importance of this step. It may seem obvious and straightforward–and maybe it will be–but it can substantially improve the quality and effectiveness of an education-outreach project.

There also exists an equally valid set of learning goals that complement and add to content goals. A recent publication by the National Science Board, *Learning Science in Informal Environments: People, Places, and Pursuits*,[2] enumerated six strands of learning. As the title suggests, the publication explicitly addresses learning within informal science environments, but much of the FEd community’s education-outreach efforts fall into that category, and many characteristics of effective informal education resemble effective formal education. A noteworthy characteristic of these strands of learning is that content makes up only 1/6 of them; a large portion of learning happens around non-content-specific strands. Additional types of learning include becoming excited about science, developing and conducting experiments, reflecting upon science as a way of knowing, participating in science, and personally identifying with science.[3] Considering these goals at the outset of a project will make it more robust and impactful.

A final step in preparatory goal-setting is to streamline, simplify, and reduce. I have yet to witness the development of an education-outreach project where the goals started as too succinct and too simple. In contrast, both researchers and education professionals begin with learning goals, especially content ones, that are too lofty and too numerous. If in doubt, simplify and reduce. Additionally, it is also completely appropriate, if not wise, to revisit learning goals throughout the development process and revise them as you obtain feedback from audiences and gain experience leading the project.

Know Your Audience

One of the most important rules in education-outreach is “know your audience”. That can prove challenging at times because you might not be able to forecast who your audience will be in advance, especially with some events like large-scale expos or science shows. With other situations, such as an undergraduate course, you can. Either way, collecting a baseline of information and taking that into consideration during development and delivery of your project can dramatically increase its effectiveness.

Fundamental audience characteristics to consider include: age, gender, race, ethnicity, and socio-economic status. Additionally, it is also important to understand your audience’s prior knowledge as much as possible, to understand what they know, how they formed that knowledge, and what preconceptions they might bring to the event. Resources exist that can help us develop a basic understanding of the ideas and concepts that students and public audiences have mastered at different ages and grade levels. Several of these include:

- The *National Science Education Standards*[4]
- The *Atlas of Scientific Literacy, Volumes 1 and 2*[5]
- National Science Teachers Association (NSTA) journals[6]: *Science and Children* (elementary school), *Science Scope* (middle school), *The Science Teacher* (high school), and *Journal of College Science Teaching* (undergraduate)
- The most recent *Science and Engineering Indicators* (currently 2010)[7]

Browsing these sources, especially the *Standards* and the *Atlas*, offers a quick way to assess the concepts that students are learning–and are capable of learning–at different ages. I emphasize the capability component because we often assume that if we just explain something well enough, children will understand it. However, some concepts, such as atoms and the particulate nature of matter, are beyond what children younger than middle school can comprehend. No matter how well you explain the idea, young children's minds and understanding of the world make it so that they cannot truly grasp the concept. The NSTA journals are likewise good sources to assess the content students learn at various levels, as well as the ways that educators help students to learn the content. The publications listed here can help you understand your audience and give you ideas for education projects.

These K-12-related resources can also be helpful for assessing the average American adult's understanding of science, which is generally considered to be at the eighth grade level. This means that if you learn about the comprehension level of middle-school students, you will also have an approximate baseline for the general American adult population. Another way to become more familiar with adults' understanding and perception of science, as well as the sources where they find their information, is the *Science and Engineering Indicators*. The *Indicators* are a series of biennial publications by the National Science Board that report on the American and international scientific research enterprises and on the public understandings of science around the world, with a focus on the US. T*he Science and Engineering Indicators 2010* is the most recent release.

Written sources are good starting points for helping us to understand our target audiences, but first-hand experience is always best. Reading about students and classrooms can only go so far; to develop a real understanding of and appreciation for the realities of your target audience, you must experience it. If possible, visit a site that serves your target audience so you can witness the reality of that environment. It does not have to be extensive–it can even be sitting in one or two class periods or visiting a local museum and informally observing visitors' interactions.

Collaborate: Form Partnerships and Leverage the Expertise of Others

An unfortunate mistake many people make when exploring education-outreach is trying to do it all on their own. Even a recent article in *Nature* supports this mistaken notion that researchers are left unaided to develop education materials and engage in outreach efforts.[8] The reality is that a wide range of groups, institutions, and professionals exist who are interested in working with scientists on education-outreach efforts. Forging and cultivating such partnerships allow us (and our partners) to divide the workload and take advantage of a range of expertise areas, thereby strengthening the entire project.

Some potential resources and partners to consider include:

- Museums, including children's museums, natural history museums, science museums, and art museums;
- Area K-12 teachers, schools, and/or districts;
- Professional societies (like APS) and their education committees (like FEd) and staff (APS has excellent education-outreach staff);
- Community groups, such as Girl Scouts, Boy Scouts, Boys & Girls Clubs, 4H, etc.; and
- Your own institution. Many universities, colleges, government labs, and industries have pre-existing education-outreach programs and infrastructures.

Asking for help, i.e., seeking collaborators, is not only acceptable, but also ideal. A strong partnership will strengthen the work and impact of both partners.

And Listen: Evaluate and Assess, Don't Assume

Evaluation is an essential component of all stages of education-outreach projects and programs. Good scientists review the current literature before conducting an experiment on a specific topic and conduct several tests to make certain that their data show what they are claiming they show. The same should be true with education efforts. Conduct some work at the beginning of the project and conduct evaluation at several points throughout the development process. Evaluation could serve as the topic for an entire newsletter article, so I will only address it briefly here, highlighting a couple main ideas. The first of these is something called front-end evaluation, and the second is formative evaluation

Front-end evaluation is the process of finding out more about your audiences–who they are and what they know–as well as what other programs have been conducted similar to yours. A research analogy to front-end evaluation would be conducting a literature review. You can learn from the work others have done before you. I mentioned earlier several resources for understanding your audience, and I strongly recommend taking advantage of the written publications and first-hand experience opportunities. Additionally, to learn more about similar education-outreach efforts, both current and past, talk with colleagues, search award databases of major funding institutions like the National Science Foundation, and attend education symposia and sessions at professional society meetings. APS has a very rich portion of each meeting's program dedicated to education. These sessions are a wealth of information and contacts for anyone interested in participating in education-outreach.

Formative evaluation is a process by which you ascertain whether your project or program is working and whether you are on the right track toward achieving the goals you established. There are a large variety of approaches that formative evaluation can take, depending on your goals, audience, and type of project. As I mentioned, this is a large topic, but several questions to ask yourself at the beginning of designing your evaluation are, "What do I want to find out? What kinds of questions should I ask in order to find out that information? And what kinds of evidence can I realistically gather and measure that would provide me with that information?" If you established strong, clear goals at the beginning of your project, the formative evaluation process will be much easier. Use these goals to frame your evaluation. Collaborators can also contribute to evaluation efforts. Professional educators such as teachers and museum staff are experienced in assessing their learners' experiences. Take advantage of their knowledge. Evaluation may seem to be a daunting task, especially for those new to education-outreach, but, again, by working with others and learning from others have done, it can become manageable and extremely helpful.

A Last Thought: Take Advantage of Passion and Enthusiasm

My final recommendation strays from Vanilla Ice's lyrics, but is perhaps one of the most vital components of effective education-outreach. As with anything you want to do well, start with areas that you are knowledgeable, passionate, and enthusiastic about. For many of us, education-outreach is "extra", something added to our already full plates of research, administration, service, teaching, mentoring, and more. That, combined with the fact that a person's passion for their topic is arguably the most important component of an education-outreach effort, makes it crucial that we choose education-outreach projects that play to our strengths, expertise, and passion. Share your passion. It is the most important thing you have to give, even if it is not mentioned in a hip-hop song from 1990.

Acknowledgments

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Greta Zenner Petersen the Director of Education for the University of Wisconsin Materials Research Science and Engineering Center (MRSEC) on Nanostructured Interfaces, where she has been sharing cutting-edge research with non-technical audiences and enjoying the fun of education-outreach for nine years.

Human Subjects Research Training and PER

David Sitar and Marshall Thomsen

In almost all cases, physics education research (PER) involves human subjects and hence is often governed by regulations associated with human subjects research (HSR). In particular, individuals involved with federally funded research are required to receive some form of training in the regulations and ethical issues associated with HSR. Since most PER takes place in colleges or universities where the bulk of the HSR is not education-related, training programs are often not designed with PER in mind.

We performed an informal survey of twenty randomly selected institutions distributed among the 4 tiers of the Carnegie classification system. We found that 60% of institutions relied heavily or exclusively on the modules produced by the Collaborative Institutional Training Initiative (CITI) program. This choice is not surprising since the CITI group has developed an extensive collection of modules specifically for HSR training, and they have a well-structured website to assist institutions in establishing and monitoring their training programs. The CITI modules have become a widely accepted, low resistance path to satisfying regulatory requirements involving ethics education in the area of HSR.

We would like to sound a note of caution, however, in relying on the CITI modules for those involved in PER. These modules address a very wide audience and thus necessarily contain information unlikely to be relevant to those involved in PER. Depending on how the institution structures its HSR educational program, a physics education researcher may wind up reading material on research involving prisoners, for instance. This problem can be addressed within the institution by working with the appropriate overseeing body (likely, the Institutional Review Board) to ensure that a certificate of completion can be earned upon completion of only those modules relevant to PER.

A second problem that arises with the CITI modules is that there are several that have topics that could be of relevance to educational research but the connection is not explicitly made, and a significant portion of the remaining information irrelevant to PER. These modules include History and Ethical Principles, Defining Research with Human Subjects, Basic Institutional Review Board (IRB) Regulations and Review Process, and Assessing Risk in Social and Behavioral Sciences. These modules do contain information relevant to the PER community, but some effort is required to extract this relevant information.

What is lacking in the CITI modules is a single module that comprehensively addresses the issues that arise in education research at the postsecondary level. The two existing modules that are most closely related are, The Regulations and the Social and Behavioral Sciences, and Students in Research. The first of these addresses issues surrounding "exempt" research, a category that education research often (but not always) falls into. The second of these has a section entitled "Students as Research Subjects" that addresses a number of key issues arising in PER, such as how to avoid coercion or the appearance of coercion in getting informed consent from your own students. However, this module explicitly indicates it is intended for students (as opposed to faculty) performing research. Taken as a whole, then the CITI modules do not address directly or in sufficient depth a number of important issues in PER, including

- What privacy issues arise when videotaping of class sessions is used as a research tool?
- Even if a particular classroom research project is considered "exempt", under what circumstances is an instructor ethically obligated to solicit informed consent from students?
- Is it permissible to use feedback freely given by students (such as course evaluations) as data in PER when the students were not informed that it would be used that way?
- What confidentiality considerations are relevant when analyzing student grades and individual submissions of required work?
- If one designs a study to test a new form of instruction and it becomes clear part way through the term that the new method is not helpful to the students, is it acceptable to continue using this method in order to complete the study, or must the study be terminated so that the instructional method can be changed?
- Is it possible for students in a small class to feel free of coercion as far as participating in a study goes, especially in cases where they expect to have the same instructor in a future course?
- More generally, is there a fundamental conflict between the faculty/student relationship and the researcher/research-subject relationship that no amount of identity concealing can mask?

Given that the CITI modules are the most widely used form of training for those who participate in HSR in a university setting, it is important that the modules appropriately address the needs of the PER community. As presently structured, the modules do not address important PER issues in sufficient depth. Moreover, extracting the information that is of relevance may result in wading through material mostly directed at a different audience. We believe this problem could be remedied by designing a module that focuses on education research at the university level. This module would be similar in spirit to the previously discussed Students in Research module in that it would pull together all of the relevant components from the other modules and add new material to address issues peculiar to education research. Until such a module is developed, however, those active in PER will need to be especially vigilant to make sure that HSR training comes as close as possible to meeting their needs, given the resources that are presently available.

It is a pleasure to acknowledge useful insights into the field of education research from Beth Kubitskey, Ernest Behringer, Elizabeth Gire, Brad Ambrose, and Charles Henderson.

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Gordon Research Conference on Physics Research and Education 2010

Topic: Laboratories and Experimental Research in Physics Education

Chandralekha Singh and Enrique Galvez

The "Physics Research and Education" (PRE) series of Gordon conferences focus on how research in physics and research in physics education can be integrated to improve the teaching of physics primarily at the undergraduate level.

Special attention is given to areas of current research and technological interest, physics education research in the focus area, and innovative curricular materials and approaches. The goal is to bring together workers who are doing cutting-edge research in physics, researchers in the field of physics education, and physics teachers so that they can all benefit from each other's expertise. In this way physics education researchers, curriculum developers and others interested in teaching physics get an opportunity to learn about and incorporate contemporary research in physics. Similarly, researchers in physics learn about physics education research, issues in pedagogy, curriculum development, and communicating and teaching physics to students at all levels.

Contemporary teaching methods developed from physics education research have been successful in improving student learning when they have been applied correctly.

However, many faculty members are not using these methods beyond the introductory courses. Most workers actively involved in cutting-edge research have little interaction with those who are developing new curricular materials and the newly emerging group of physicists specializing in physics education research. The conferences in this series bring together all three groups so that novel ideas about physics teaching, learning, and research emerge.

The focus area of the PRE Gordon conference changes each time. In 2010, the Conference focused on Experimental Research and Laboratories in Physics Education. The goal was to gather educators and researchers for presentations and discussions on ways to improve the role of experimentation in the physics curriculum.

The conference gave the physics community an opportunity to rethink these ideas and learn of success stories. The format of the conference involved morning and evening plenary sessions followed by discussion periods. Afternoons free of scheduling offered opportunities for informal interactions and exchange of ideas. Poster sessions offered participants a forum for presenting their own work. College and university faculty, laboratory instructors, post-docs, graduate and undergraduate students, and equipment developers participated in the conference.

The participants brainstormed how the technological advances and the focus on assessment have led to numerous changes in the physics curriculum. Since laboratories and role of experimentation have not received the comprehensive attention that they deserve, the following were some of the many topics discussed at the Gordon conference: How should we best use laboratories in the introductory sequence? Are there new ideas and models that work better than the conventional approach? What is the right balance between experimentation and simulation? What new types of experiments are available due to modern technology? What innovative laboratories for upper-level courses have been developed? Should the advanced laboratory be a research experience? What table-top technologies provide the best settings for modern advanced laboratories? What research problems have found their way into the advanced lab? What is the value of a capstone research experience, which in most cases is dominated by experimental projects? How can we effectively involve undergraduates in scientific research as part of the undergraduate physics curriculum? Should we make innovation a part of the undergraduate physics curriculum?

Chandralekha Singh and Enrique J. Galvez were co-chairs of the 2010 Gordon Conference on Physics Research and Education. Chandralekha Singh is an associate professor in the Department of Physics and Astronomy at the University of Pittsburgh and the chair-elect of the APS Forum on Education. Enrique Galvez is a professor in the Department of Physics at the Colgate University.

Undergraduate Research at the LHC

Sarah Eno

When the Large Hadron Collider (LHC)[1], a proton-proton collider located outside of Geneva, Switzerland, achieved a center-of-mass energy of 2.36 TeV on Dec. 13, 2009, it became the new energy frontier for accelerator-based studies of particles and their interactions. The previous holder of this title was the Tevatron, a proton-antiproton collider located outside of Chicago, Illinois, which began its operations in the early 1980's. Since most of the students who are currently studying at our undergraduate institutions were born after the turn-on of the Tevatron, the LHC startup was their first opportunity to experience the excitement of crossing an energy frontier, with its potential for the direct discovery of new particles. Many undergraduates learned about the LHC, and the physics that will be studied there, from reports on the news, from departmental physics colloquium, and even from downloading "The LHC Rap"[2]. However, since the start of U.S. involvement in the LHC, undergraduate students at U.S. institutions have also been intimately involved in the work that made data taking with this new facility possible. They were involved in every aspect of the design and construction of the LHC detectors, the design of data-analysis strategies, and construction of suitable computing environments. In this article, I review various programs that allow U.S. undergraduates to become involved in this cutting edge research.

The most common way for undergraduate students to become involved in LHC research is through participation in one of the existing research programs at U.S. universities or national laboratories associated with the LHC's four major detectors, ALICE[3], ATLAS[4], CMS[5], and LHCb[6]. ATLAS and CMS are the two largest experiments. At the time of the writing of this article, 48 U.S. universities and national laboratories are members of the CMS collaboration, and 44 are members of ATLAS. Most of these institutions have at least one undergraduate student working with their group. Some universities, for example Cornell, the University of Kansas, M.I.T., the University of California at San Diego, CalTech, and the University of Florida have on order 10 students per year. Students often work on a project at their University during the academic year, and often go to CERN, the host laboratory of the LHC, during the summer. Students can work on a wide variety of projects. Students majoring in either computer science or in physics at the University of California, San Diego, for example, do essential work on the distribution of the vast amount of data produced at the CMS experiment to institutions in the United States. Students at other universities have worked on projects relating to, for example, calibration of temperature sensors, detecting excess muons from solar flares, calorimeter electronics construction and calibration, muon identification algorithms, electronics for silicon detectors, search strategies for fermiophobic Higges, search strategies for ADD Large Extra Dimensions, improving the sensitivity for SUSY searches using multi-variant techniques, and cosmic ray data analysis with ATLAS. Students at Cornell can enroll in a two-semester course on LHC research and then spend the summer at CERN. This course is also open to students from other universities, although most of the enrollment is local.

The National Science Foundation (NSF) also sponsors some larger, enhanced programs. Some give enhanced opportunities to undergraduates at their own institutions, while some allow students at any U.S. institution to participate in LHC research. An example is a joint program between Nebraska, Kansas, Kansas State, U. Illinois Chicago, and U. Puerto Rico Mayaguez, in the U.S., and the Paul Scherrer Institute and the Eidgenossische Technische Hochschule in Germany[7]. This program allows students at these institutions to learn the latest in the design of silicon-based detectors and to spend time abroad at a participating institution. A program at Boston University[8] allows students to spend a semester at the University of Geneva with an emphasis on LHC physics. The largest and most well-known program is an REU program run by the University of Michigan[9]. This program has sent on order 15 students to CERN each summer, from a variety of undergraduate institutions, since 2001. It is sponsored by the NSF, the University of Michigan, and the Ford Motor Compnay. Unfortunately, none of these programs yet reach the achievement of the program sponsored by CERN for students from CERN member states.[10] This program brings students to CERN for thirteen weeks in the summer. They spend half their time working with mentors, who are assigned to them, on an experimental project, and the other half attending lectures by world-renowned experts. It would be nice if American students could also have such an opportunity.

Many students who have participated in these programs have continued on to Ph.D. research in particle physics. They generally are satisfied with their experiences, which emphasize international collaboration, working in large groups, and cutting edge science. With the LHC experimental program now actively taking data, the opportunties for interesting research will continue, perhaps, as with the Tevatron, for the next 30 years.

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(Endnotes)

1. http://lhc.web.cern.ch/lhc/

Figure 1 Former University of California at Irvine undergraduate Milton Bose worked on the CMS detector (shown) under the tutelage of Professor Gail Hanson

Figure 2 Students involved in the University of Michigan REU program learn more about the LHC from Professor Homer Neal at CERN

2. http://www.youtube.com/watch?v=j50ZssEojtM
3. http://aliceinfo.cern.ch/Collaboration/
4. http://atlas.web.cern.ch/Atlas/Collaboration/
5. http://cms.web.cern.ch/cms/index.html
6. http://lhcb-public.web.cern.ch/lhcb-public/
7. http://physicsweb.phy.uic.edu/pire/index.html
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Undergraduate Research: Faculty Scholarship and Undergraduate Education

Peter J. Collings

A meaningful research experience is an important part of a quality undergraduate education in physics and astronomy. It is the responsibility of faculty to offer such opportunities, just as it is their responsibility to offer a sequence of courses and laboratories. There need not be a conflict between research productivity and the participation of undergraduates. But for this to be the case, careful planning by faculty as well as the use of faculty skills as teachers and researchers are required. I have been supervising undergraduates in my research laboratory for almost four decades. In this article I explain a little about my research program and then go into more detail concerning the aspects of faculty scholarship and undergraduate education that come into play when undergraduates conduct research.

Experimental Soft Condensed Matter Research
Soft condensed matter research concerns fluids that are more complex than simple liquids. There is quite a large range of fluids that fit into this category; polymers, liquid crystals, emulsions, and colloidal suspensions are some examples. My research for the last 38 years has concerned liquid crystals, a state of matter that is fluid, but for which the molecules retain some degree of orientational order and sometimes positional order as they diffuse throughout the sample. As a specific compound is heated in the solid phase, at a precise temperature it undergoes a phase transition to the liquid crystal phase, losing most of the orientational and positional order it had in the solid phase. At a higher temperature, the liquid crystal phase undergoes a transition to the liquid phase, at which point it loses all orientational and positional order. The degree of order in a liquid crystal is small, so in some senses it resembles a liquid more than a solid. This is borne out by the latent heats of transition. A typical latent heat for the solid to liquid crystal phase transition is about 300 J/g, while a typical latent heat for the liquid crystal to liquid phase transition is only 30 J/g.

The presence of order makes properties of a liquid crystal depend on direction, so rather than being isotropic, they are anisotropic. For example, light polarized along the preferred direction of orientation has a different index of refraction from light polarized perpendicular to the preferred direction. This makes liquid crystals birefringent. In fact, the amount of order in a liquid crystal can be determined by measuring the difference in properties along different directions. Early in my career, I used the fact that the splitting of nuclear magnetic resonance lines depends on the molecular orientation relative to the magnetic field to measure the order in a liquid crystal. More recently, I utilized the difference in the absorption of light polarized along different directions (linear dichroism) to determine the degree of order.

Compounds that form liquid crystals when pure are called thermotropic liquid crystals. The active material in liquid crystal displays is a mixture of several such compounds. Liquid crystal phases are also formed when certain molecules are dissolved in a solvent. The most common examples are soaps and phospholipids, which form structures of ordered molecules when mixed with water. The structures in soap solutions are where oils can be “dissolved” and the double layer of phospholipids is the basic structure of the cell membrane. When such structures form in solution, they are called lyotropic liquid crystals. One less studied example of these is the liquid crystal phase formed when certain dye molecules form aggregates in water. These aggregates result from the spontaneous stacking of molecules, and it is the aggregates that have orientational and sometimes positional order as opposed to the molecules in a thermotropic liquid crystal.

These spontaneously aggregating systems have been the subject of the investigations in my laboratory for the last 7 or 8 years. The work is quite interdisciplinary, with techniques and concepts drawn about equally from physics and chemistry. Soft condensed matter research is characterized by the use of many techniques. Recently, my students and I have utilized absorption spectroscopy, x-ray diffraction, polarization and confocal microscopy, and magnetic birefringence. Most of this work has been preformed at Swarthmore College, but some has been done at the University of Pennsylvania and the National High Magnetic Field Laboratory at Florida State University.

Typically 2 or 3 students work in my laboratory for ten weeks over the summer, and 1 or 2 students do experiments during the academic year. The stipends for the summer students come from various sources, including research grants from National Science Foundation and the Petroleum Research Fund, the Research Experiences for Undergraduates Program at the Laboratory for Research in the Structure of Matter at the University of Pennsylvania, grants from the Howard Hughes Medical Institute to Swarthmore College, and Swarthmore College funds. On average, about two articles in peer-reviewed journals are published each year reporting on results from my laboratory, and undergraduates are co-authors on most of them.

A Faculty Member’s Responsibility
Providing research opportunities for undergraduate students is part of a faculty member’s responsibility for faculty at both research universities and predominately undergraduate institutions. Sometimes this responsibility is written into the contract; more often it is a specific criterion for promotion and tenure. In some cases this responsibility is only communicated verbally, especially at the time of hiring.

The reason more and more institutions are including undergraduate research as a responsibility of the faculty is that the quality of an undergraduate science program is increased by opportunities to conduct publishable research. There have been studies done to assess the outcomes from undergraduate research experiences, and all point to gains in self-confidence, motivation, and academic success [see S. H. Russell, M. P. Hancock, and J. McCullough, *Science* **316**, 548, (2007) for example]. Many organizations have realized this and have issued statements supporting undergraduate research for as many physics and astronomy majors as possible. Two examples are the American Association of Physics Teachers and the Committee on Education of the American Physical Society.

Some major programs in physics require the writing of a thesis, which is often based on the research done by the student. Many other departments encourage all students to do research but don't require it, often instituting programs on campus to allow undergraduates to do research, and in addition, assisting their students as they apply for research experiences elsewhere.

It should be pointed out that providing undergraduates with research experiences should be seen as a responsibility of the institution also. Given the teaching and scholarship responsibilities of faculty, it is unrealistic to imagine that on their own faculty can provide such experiences to a large fraction of majors. Institutions must provide both financial and infrastructure support, whether it be funds for student stipends, administrative support for coordination of the undergraduate research program, or the necessary facilities to allow large numbers of undergraduates to participate in research.

Faculty Scholarship vs. Student Education

There certainly are challenges when faculty provide opportunities for undergraduates to participate in their research program. Some theoretical research requires mastery of advanced mathematical techniques and a firm understanding of advanced physics concepts. Some experimental research is done using equipment that is expensive, easily harmed, and requires an extensive amount of time to learn how to use correctly. Other experimental research is done off campus, at national facilities or the institutions of collaborators.

Many faculty have shown that these challenges can be overcome by careful planning. Proposals must include funds for what is necessary, whether it be equipment, stipends, travel money, or training activities. Over the years resources must be assembled so undergraduates can participate in the research either on campus during the academic year or off campus during vacations. Faculty also must pay careful attention to the wide range of research questions that are possible. Some may be more accessible to undergraduates and/or require a work schedule more compatible with the academic calendar. Finally, faculty must consider each particular undergraduate student, arranging a project and schedule that is appropriate considering the student's academic background and laboratory experience. This is an important task both before the undergraduate begins to do research and while the research is taking place.

Mentoring Undergraduate Research Students

The quality of an undergraduate research experience often depends on whether the research is at the forefront of current work in the field. Faculty members must use every means possible to keep their research program as productive as possible. All options should be utilized, including collaborations, the involvement of students at different levels of expertise (undergraduates, graduate students, post-doctoral fellows), sabbatical leaves, different locations, different parts of the academic year, and the number of researchers working at any time. Manuscripts must be written and submitted in a timely way. This is important both to keep the research an important part of the scientific enterprise and to give recognition to the people responsible for the research. The point here is that with proper planning the participation of undergraduates in a research program need not be at odds with productivity. In fact, careful planning can produce just the opposite outcome. Undergraduates working on a research project can actively contribute to it in important ways.

No teacher walks into class without preparing ahead of time for what is going to be presented. Likewise, no faculty member should engage undergraduates in research without preparing adequately in ways that maximize the chance for a successful experience. This preparation may extend back as far as the selection of the research area, choosing one for which it is easier to provide meaningful opportunities for undergraduates. Deciding which of the possible projects an undergraduate will work on is another element of the planning process. Such a decision must take into account the background and goals of the student, assigning the student to a project for which there is a good possibility of success. Finally, the planning process must include an early consideration of what resources must be in place for a productive research experience. The time undergraduates can devote to research is usually quite restricted. Time lost waiting for equipment and supplies to arrive must be kept to a minimum.

Careful planning must be taking place even while the undergraduate conducts research. Being new to the field of research, it is important that background information, whether it be the theoretical foundation or prior work in the field, be acquired by the student. This can be a formidable challenge, as most students do not know how to read the scientific literature and how to do a literature search. In many cases this is best done through activities that are not directly necessary to the research program, like taking the time to go through a few critical papers in the field, not just to give some background to the project, but to show students how to read research articles.

Thought should also be given to how the student can gain expertise in a gradual and systematic way. What tasks done early will allow the student to take on other tasks later? What order of research activities will help to build up some independence in the student? Expecting students to perform tasks for which they are not sufficiently prepared can be exceedingly discouraging, with the potential to sabotage the entire research experience. Faculty members should also look for opportunities for students to make some research decisions. This is exceedingly important, since this is the best way for the student to become invested in the research question and understand the scientific process. This can be a real challenge when collaborations are involved. If only the faculty member discusses the project with collaborators, the students are missing a real opportunity to observe and perhaps play a role in the scientific enterprise. Finally, part of the research endeavor is the presentation and dissemination of the results. Faculty members should take advantage of opportunities for students to present their work orally and in some written form. Understanding how this is done is not something students can uncover on their own; they must be guided through the process of presenting their work.

Benefits of Undergraduate Research to Faculty

Providing meaningful research experiences to undergraduates is hard work, requiring skill as both a teacher and a researcher. Thankfully there are benefits to the faculty who take on this responsibility. Being able to allow undergraduates to participate in cutting-edge research can be an incentive to do those tasks that keep a faculty member's research program productive. Many faculty are dedicated to their students and go to great ends not to let them down. This motivation can be a wonderful means to maintain a successful research program.

Undergraduate students often have picked up some of the newest technology, which can be extremely useful at times in the research endeavor. I recall a student who arrived with experience with image processing, allowing her to develop a new capability for my laboratory. Often research requires time consuming and repetitive work; undergraduates are often very happy to be involved in such activities, because it is new to the student and because the fruits of their efforts are usually very visible. Plus, the cost to involve undergraduates in these aspects of a research program is quite low, and often they are capable of performing the work with as much care and accuracy as any other member of a research group.

Another benefit that at times can be very important is that with so little background and experience, undergraduates sometimes come up with ideas that others would not. I can think of numerous examples in my career where a question, remark, or suggestion of an undergraduate turned out to be crucial to success, especially because it was something I would not have thought of myself. Once after observing a student acquiring data that did not make sense to me, I left asking the student to compare the data to theory anyway. The material being investigated possessed a twisted structure and the literature stated that the twist was right-handed. The student did not remember this, and fit the theory to the data assuming a left-handed twist. The fit was excellent, and not only did it teach us the lesson of not believing everything in the literature, it also cleared up discrepancies in other data we had acquired on this material.

It is also true that involving undergraduates in research allows faculty members to do some riskier science. It is important for graduate students and postdoctoral fellows that their projects bear ample fruit in a reasonable amount of time. This is not the case for undergraduates, where obtaining results of some importance is not nearly as important. In fact, the quality of the research experience for undergraduates is only loosely coupled to the significance of the results they obtain. Many students who undertook unsuccessful or partially successful projects under my direction learned far more than many other students whose projects ended with publishable results in hand.

Finally, undergraduate students are likely to be the youngest members of a research group. Having these 18-22 year olds around provides an opportunity to stay in touch with the younger generation, and perhaps slow down the faculty member's aging process slightly!

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Research with Students in Nonlinear and Fluid Dynamics

Jerry Gollub

Nonlinear dynamics refers to phenomena governed by nonlinear differential equations, often fluids. It has important interfaces with soft matter and biological physics. Fluid dynamics has important connections to astrophysics, geophysics, and engineering. The projects to be described involved a team approach: a postdoctoral researcher, one or more undergraduates, and me.

Here are some of the research questions we examined over the last few years: Do small particles accurately follow fluid flows? How do elongated particles orient themselves in a fluid? Do converging flows exhibit spontaneous swirl? When is the flow of a fluid containing particles reversible? What unique flow properties are manifested by polymeric fluids? How do swimming cells interact? I'll say just a little about each of these projects, and then comment on the role of research in Physics with students at Haverford.

Undergraduate Peter O'Malley looked at the question of whether small particles accurately follow fluid flows, working with postdoctoral fellow Nick Ouellette, now at Yale. Particles certainly do not follow the fluid if their density is different and the particles are accelerated. But what happens if there is no density difference? The question is important because particle tracking is the primary method by which flow phenomena are studied. Peter used electromagnetic forcing to drive a chaotic flow, and tracked particles of different diameter: 80 micron particles, which followed these slow flows well, to determine the velocity field, and 1-2 mm particles of the same density to look for deviations. Very significant velocity differences between particles and the local fluid elements were detected for the larger particles, and the results were published in *Physical Review Letters*.[1] Peter entered a graduate program in physics after his time at Haverford.

Subsequently, undergraduate Monica Kishore, working with Nick Ouellette and postdoc Jeffrey Guasto, investigated the question of how elongated particles orient themselves in the same type of fluid flow. Monica made excellent progress on this problem, and the eventual result, finished after her departure for graduate study in medical physics, was that particle alignment can be explained using what we call stretching fields. These fields, which can be computed from measured velocity fields, give the local strength of the stretching of fluid elements. This work has been submitted to Physics of Fluids, in collaboration with Greg Voth's group, which studied the same problem in parallel with our work at Haverford.[2] Greg had earlier pioneered the process of measuring stretching fields[3] while a postdoctoral fellow at Haverford, before joining the Wesleyan University faculty.

Undergraduate Michael Jablin looked at the question of whether spontaneous swirl exists in a converging fluid flow, as had been claimed in published work. He designed and built an apparatus to test this hypothesis, and became an expert in particle tracking to look for a small azimuthal (non-radial) velocity in converging flows. His measurements were quite sensitive, but there was no convincing evidence for the claimed effect. While this outcome was disappointing to us, the work resulted in excellent training for Michael, who obtained a job after graduation providing user support at the Los Alamos SPEAR neutron reflectometer facility. His work there led to diverse publications and eventual graduate study. So experiments don't always have to discover or characterize a new phenomenon to produce a useful educational outcome.

Undergraduate Andrew Ross worked on the reversibility of low Reynolds number flow containing particles. We knew from earlier work that such flows can be irreversible, as a result of chaotic interactions between particles.[4] Andrew, working with postdoctoral fellow Jeffrey Guasto, looked at channel flows, where the fluid is sheared non-uniformly. This work, completed after Andrew went on to work with a colleague on quantum computing, showed that channel flows can produce irreversibility everywhere, even in places where the shear is small. The results were published in *Physical Review E.*[5]

Students James Diorio and Charles Thomas, working with postdoctoral associate Paulo Arratia (now at University of Pennsylvania), studied instabilities in polymeric solutions using microfluidic flows. They detected two new instabilities which occur at low Reynolds number, where Newtonian fluids would flow without instability. The resulting paper[6] stimulated quite a bit of theoretical work and garnered 25 citations. Charles is now a graduate student at Penn in nonlinear physics, and James got a Ph.D. at University of Maryland in Mechanical Engineering.

Recently, my group has been working on the fluid flows induced by swimming algal cells only 10 microns across, which use twin flagella moving in a breaststroke pattern to propel themselves.[7] Algal cells account for a significant contribution to the world's oxygen production, and their flagella are similar to those found in some cells in the human body. Current undergraduates Andrew Sturner and Ivy Tao have been working to understand the interactions between these swimming cells. Are they mainly hydrodynamic (where each swimmer's induced velocity field advects the other cells)? Or do the cells sense each other and respond?

What happened to the postdoctoral scholars who worked with the undergraduates on these projects? they have faculty appointments elsewhere, along with independent research funding, and continue to work with students.

Scholarly investigations first became a requirement for the undergraduate degree at Haverford in 1920. I understand that Reed College was also an early adopter of this approach, and would be curious to hear of others. Undergraduate research mentoring is also built into the teaching responsibilities of faculty members. It takes a considerable time investment to make research experiences available to students, and suitably designed advanced laboratory courses can prepare them effectively (for example, see ours at http://www.haverford.edu/physics-astro/course_materials/phys326/phys326.html). Summer research opportunities are also critical for students. This past summer, 22 students did research at Haverford with physics faculty members, and 7 did so elsewhere, altogether at least 76% of our junior and senior majors. The fields represented were diverse, including quantum gravity, biological physics, nanoscale (condensed matter) physics, and near field cosmology, in addition to the work on nonlinear/fluid dynamics described in this summary. Active engagement in research has been rewarding for our students, many of whom have won awards (Goldwater, Churchill, Fullbright, NSF, Apker, etc.) At least four former research students later won NSF Career Awards when they became faculty members. Our website (http://www.haverford.edu/physics-astro/alumni/careers.php) shows the diverse careers of Haverford physics graduates, many of whom chose directions outside of scientific research. However, we believe (and they indicate) that their lives and careers have been significantly enriched by their research experiences as undergraduates.

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Finding the Time and Resources to Support Undergraduate Research

John Mateja

In an earlier *Forum on Education (FEd) Newsletter* article entitled *A Time for Action, Not another Report*, I discussed the need to increase the number of U.S. born students seeking undergraduate and graduate degrees in physics and astronomy (Fall 2009). As I reported in the article, the situation has reached a level of concern that our physics and astronomy societies have collectively called upon physics and astronomy departments across the country to provide ALL undergraduate physics and astronomy majors with a research experience, a move intended to interest and retain students in these disciplines.[1]

In this issue of the *FEd Newsletter*, Peter Collings, the current chair of the APS Committee on Education, has written an article, *Undergraduate Research: Faculty Scholarship and Undergraduate Education*, that points to ways in which research and education can go hand-in-hand, to the benefit of both. Peter argues that a well constructed and well-thought-through plan can involve undergraduates in meaningful research AND maintain research productivity. Further, he suggests that undergraduates, who bring a naiveté to the problem, can ask questions that even lead to new insights. Today, few faculty question the value of engaging undergraduates in research. For most, the issues are time and resources, topics that this article will address.

When presenting institutes or workshops on developing successful undergraduate research programs, one of my favorite PowerPoint slides asks the following question, "How soon will (place the name of YOUR UNIVERSITY here) increase the number of faculty by 30% to provide YOU with additional time to involve undergraduates in research?" It is intended to get a laugh from my audience and it always does. Everyone in the audience knows this is unlikely to occur and that, if you wait for this to happen, undergraduate research will likely never develop on your campus. The real questions are, "Are there actions one can take to support undergraduate research that better utilize existing resources or stimulate the creation of new resources?" and "Are there ways to provide faculty with more time to enable them to mentor undergraduate research students?"

Let's look at the resource question first. While I am certain there are other ideas, and I would encourage those who have developed alternate funding strategies to write future *FEd* articles on their initiatives, I have identified three interesting and successful funding strategies. These include:

1. changing existing "scholarships" to "undergraduate research fellowships,"
2. having students "tax" themselves to support a campus-wide research program, and
3. creating endowed funds to support undergraduate research.

At Morehead State University and Murray State University in Kentucky, students no longer simply receive "presidential scholarships." Today they are awarded "presidential research fellowships." What is the difference? In the past, students receiving the scholarship would be given financial support, with the hope that–without little additional guidance and or mentoring–they would succeed in college. Under this system, some students did well; other students could have done better. Today, the recipients of the "research fellowships" receive the same financial benefit but, in addition, beginning in their freshman year, they now work on research projects under the guidance of a faculty mentor. Faculty who participate in this program also help students make the most out of their undergraduate experience by providing academic advising and by providing students with the guidance and support they need to make important career decisions. In the early days of the Morehead program, faculty often had to be cajoled into taking on a freshman research fellow. Today, because of high faculty demand, there is a waiting list for these students.

Another interesting model can be found in Wisconsin. At the University of Wisconsin–Eau Claire, the students themselves understand the value of extracurricular learning opportunities like undergraduate research and study abroad and, as such, are willing to "tax" themselves to support these activities. For at least the last five years, the student government of this ~6,000 undergraduate student campus has levied a fee on the student body that has allowed it to support an undergraduate research operating budget of $500,000 (the university provides support for the staff of the undergraduate research office). The students at UW–Eau Claire understand that if the graduates of their institution are to be competitive in today's global workforce, they need more than just a college diploma. As such, they are willing to support the kinds of programs that allow Eau Claire graduates to build strong competitive resumes. The program is valued enough that next year the Eau Claire student government is raising its support for undergraduate research to $750,000.

Finally, there are a number of universities that are now developing endowments to support their undergraduate research programs. While once considered the domain of private colleges, like the $10 million dollar endowment the president of Elon University in North Carolina is working to establish for his institution's undergraduate research program, today public universities are working to develop similar endowments. The President of SUNY–Oswego, Deborah Stanley, is in the process of establishing a $10 million dollar endowment to support a very forward-thinking undergraduate research STEM initiative at Oswego. The endowment will provide students with research experiences on the Oswego campus in their freshman or sophomore year and then provide them with a second research experience during the student's junior or senior year in a laboratory in another country. Agreements to host Oswego undergraduates have been obtained in laboratories in China, Russia, Brazil, among others.

Campuses around the country are clearly developing creative solutions to generate the resources needed to support undergraduate research. Have these campuses been as innovate in finding ways to provide faculty with additional time to allow them to mentor undergraduates? As you will see, departments are also finding inexpensive and even no-cost ways to add time to faculty schedules.

As Peter Collings demonstrates in his article, one of the more important realizations is that, if properly planned and executed, undergraduate research can serve a dual purpose–it can enhance learning AND increase research productivity. While this does not "increase the number of hours in a day a faculty member has," the benefit to faculty is that their undergraduate research activities can be used to simultaneously strengthen their teaching and research portfolios. What is needed to ensure that undergraduates are "effective contributors" to one's research program? As the answer to this question is clearly articulated in Peter's article, I will not elaborate here other than to say students must be engaged in research early in their undergraduate careers and they must be provided with the opportunity to remain engaged in research throughout their undergraduate years. When this happens, students' work is often of a caliber that it leads to presentations at professional society meetings and publications in disciplinary journals. When and how students participate in research is a faculty member's prerogative. Even without additional support from the institution, faculty can design their undergraduate research program in a way that maximizes the benefits of their program to both their students and themselves.

Department chairs and/or faculty can also help build an undergraduate research program. What classes are offered, when they are offered, who teaches the classes and who serves on departmental committees are typically departmental prerogatives. Departments that support undergraduate research work to:

1. minimize the number of faculty preps in a given semester (e.g., by providing faculty with the opportunity to teach multiple sections of the same course),
2. minimize the number of new courses faculty are asked to teach,
3. provide research active faculty with a least one day per week when the faculty member is not teaching a class,
4. build undergraduate research into departmental tenure and promotion guidelines (and also encourage the inclusion of undergraduate research in university tenure and promotion guidelines),
5. minimize the committee service for faculty who mentor undergraduate research students, and
6. creatively award teaching credit for mentoring undergraduate research students[2].

While these are clearly difficult financial times and most universities are struggling to make ends meet, there are institutions that are finding creative ways to support and enhance undergraduate research on their campuses. As undergraduate research is rapidly becoming a baseline against which academic programs are being judged, these programs are positioning themselves to become the leaders in our community. For the health of our individual programs and for the health of the physics and astronomy communities as a whole, it is incumbent upon all of us to continue to work to build robust undergraduate research programs on all of our campuses.

1. American Physical Society's Committee on Education, Society of Physics Students, American Astronomical Society, Council on Undergraduate Research's Physics and Astronomy Division, and American Association of Physics Teachers
2. On a growing number of campuses, students have the opportunity to sign up for one credit hour of research per semester. Departments and colleges are reluctant to reduce a faculty member's teaching load for mentoring one or two such students when the total number of credit hours produced is this small. Departments have devised a number of ways to address this problem. Some departments allow faculty to bank student credit hours until they have accumulated a total of 10 student credit hours. The concern with this approach is that it could take a faculty member up to 10 semesters (i.e. once every five years) to earn a single course release. As reported to me by Bert Holmes, a former faculty member at Lyon College, a different approach was developed at Lyon College. All student research credit hours generated during a given semester in a given department were awarded to one faculty member who was then the "faculty of record" for all student research during that semester. Using this approach, there was sufficient time generated every semester to award a faculty member with a course release. The "faculty of record" position was rotated among the research active faculty, thereby ensuring that every semester a different faculty member received release time for mentoring undergraduate research students.

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Teaching Innovation Through Undergraduate Research

John R. Brandenberger

This note reports on a three-year investigation into the *teaching of innovation* being conducted in the Department of Physics at Lawrence University. *Innovation*, which always involves new ideas, risks and rewards, and successes and failures, may be excessively oversold nowadays, but we physicists at Lawrence take it seriously because we believe that successes in the *teaching of innovation* will ultimately help solve problems ranging from the slippage in US competitiveness to various global issues associated with energy, water, health, and nutrition.

The current investigation was prompted largely by the 2005 NAS report, *Rising Above the Gathering Storm (RAGS)*. This very important report is daunting but intriguing because it identifies problems to which we physicists at Lawrence feel we can contribute. Developed by Nobel laureates, academics, and CEOs, *RAGS* carefully documents the current *slippage in US competitiveness* and the fact that US prosperity hinges on high-quality jobs–the creation of which depend largely upon science, engineering, technology, and *innovation*. The US led in these areas during the 20th century, but we are ceding that leadership today. *RAGS* also emphasizes that scientific research creates new knowledge, which, when combined with creative engineering, generates innovative companies that create new jobs and prosperity. We see *RAGS* as *throwing down a gauntlet regarding innovation*, and we are picking it up to explore how to better teach innovation.

By the way, we view innovation as an effort *that employs new ideas or approaches to improve products or strategies that draw upon important antecedents . . . , or, . . . an effort that involves a lengthy process of accretion resembling the manner in which an oyster wraps layers of nacre around a grain of sand to create a pearl*. The question arises whether innovation can be taught? Some doubt it, while others argue that it is best done in the humanities. We believe, however, that *scientific research programs offer very promising settings for the teaching of innovation*. We also believe that physicists, perhaps better than most individuals, appreciate that *innovation must occupy center stage in a research program, or that innovation serves as the lifeblood of such a research effort*. Hence we believe that research programs should serve as excellent environments within which to incubate innovative undergraduates. We are testing that conjecture.

During both the summers of 2009 and 2010, we used our own ongoing research programs in astrophysics, biophysics, spectroscopy, surface physics, plasmas and EIT to support this study. Six faculty members and undergraduates were involved each summer, and we used the following five-step procedure to superimpose innovation activities onto our existing research programs:

Step 1 (week 1): After viewing the video *Deep Dive* filmed at IDEO, we discuss idea generation, the efforts of Thomas Edison and Steve Jobs, brainstorming, prototyping, the dictum "Fail Often to Succeed Sooner," and the importance of perseverance and expertise.

Step 2 (weeks 1-5): While acquainting themselves with their research programs, we urged them to try to conceive *innovative changes* that might improve their programs.

Step 3 (weeks 4-7): Next we encouraged *brainstorming* of the likely cost and merit of these changes.

Step 4 (weeks 7-8): We then considered implementing the changes using alternate technologies.

Step 5 (weeks 8-10): Prototypes of the changes were developed, refined and incorporated.

Based upon the collected results of two summer offerings, we believe that our approach is working, i.e. it seems to be encouraging innovative behavior and mindsets on the part of our students. To enliven the investigation, we use questionnaires, perusals of student notebooks, rubrics to probe the acquisition of character traits associated with innovation, student presentations, and outside experts to assess the program. Our fifteen rubrics, based upon fifteen character traits associated with innovation, help us measure whether our students are increasing their *originality, creativity, practicality, productivity, risk-taking, tolerance for ambiguity, team participation, vigor, connectivity, insightfulness, articulateness, curiosity, divergent thinking, inclusiveness, and self-reflection*. The rubrics, six of which appear below, are scored from 5 (high) to 1 (low) by faculty in "one-on-one" conferences with students three times each summer:

1. **Originality**: Successful innovators develop strong predilections to conceive new ideas, strategies, approaches, and/or processes that bring value to their endeavors.

2. **Creativity**: The most able innovators generate particularly imaginative ideas for which there are no antecedents. We reserve the word *creative* to describe this level of thinking.

3. **Practicality**: Innovative physicists tend to emphasize practical matters (e.g., ideas, strategies, processes, or devices) characterized by utility, intrinsic value, and useful function.

4. **Risk-taking**: Successful innovators willingly assume risk of failure because they know that failure can be instructive. Some endorse the dictum, "*Fail often to succeed sooner*."

5. **Tolerance of ambiguity**: A successful innovator is comfortable operating in areas characterized by complexity, asymme-

try, and uncertainty.

6. **Team participation**: Innovators embrace cooperation, team play, and flexibility.

Figure 1 provides plots of the average scores for six of the fifteen rubrics and all nine of our research students during the summer of 2009; "baseline" corresponds to the beginning, "midpoint" and "final" to the middle and end of the summer. Note that the trends are upward suggesting that we are making headway in shaping thinking and behavior. The plotted points show that show statistically significant changes over the course of the summer are underlined on the charts, and the opinions of the visiting panelists are shown on the right.

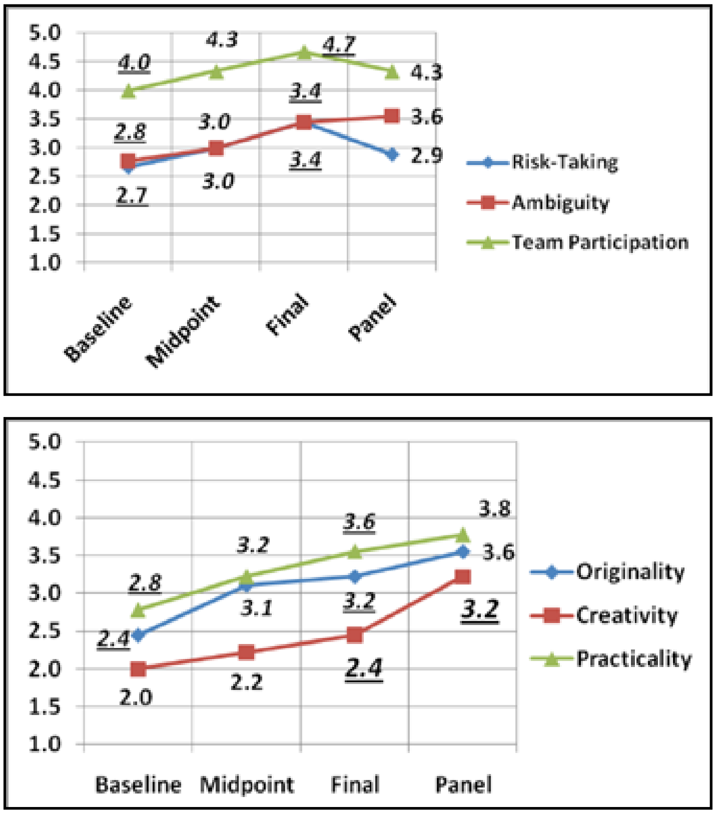

Fig. 1. Plots of averaged scores for nine student researchers on six of the fifteen rubrics.

Late in both summers, three visiting Ph.D. physicists interviewed our students and reported the following: the frequent brainstormings along with the dictum *Fail often to succeed sooner* and the *Deep Dive* video made major impressions; the program was extremely compressed, but the students thoroughly embraced innovation; our emphasis on speaking skills was appreciated; students appreciated the greater freedom when supervisors were absent; and student attitudes toward risk, creativity, and divergent thinking were reinforced.

Overall, this investigation, which is based on six coordinated summer research programs, each outfitted with innovative overlays, seem to be successful. Substantial research progress was made in each of the research groups Some of the more notable student achievements include:

- Two students modified a torroidal plasma vessel so that a filament could be extracted without breaking vacuum The mechanism and drive unit were actually incorporated into the vessel.

- Two students extended some well-established code for simulating the creation of extrasolar planets; they improved the treatments of boundary conditions among other things.

- One student examined EIT in Rb vapor subject to a weak magnetic field. She improved the setup, modified the Labview control program, and took preliminary power-dependency data.

- Three students investigated the mechanics and transport of single biological polymers using a laser-based microscope. They developed better labeling and detection schemes.

- To measure splittings in the 2F states of 87Rb, one student removing non-linearities in the laser sweep and became co-author of a paper (*Phys. Rev A* 81, 032515, 24 March 2010).

While *innovation* provided the unifying theme for the past two summers in these offerings, most of the work focused on the actual research. Students concentrated on learning the strategies and goals of their respective programs. Since all six programs were capable of generating publishable results, the overall expectations were quite challenging especially for the students who had completed only two years of physics. We learned that imposing the innovation expectation was a taller order than anticipated. As a result, the actual innovative achievements of the students fell somewhat short of our expectations because the students were too hard-pressed trying to understand the basic physics in their respective groups.

We remain convinced, however, that research programs can serve as effective incubators of innovative thinking. To improve the situation, we are adopting a strategy in which "less is more," whereby we are suggesting that students strive for a mastery of only *part of* the individual research agendas. In this way we hope that each program can provide more time for innovative thinking and action. We are also meeting weekly with our upcoming research students during the spring term prior to the summer effort to help bring them up to speed regarding research objectives.

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Undergraduate nonlinear dynamics course at Cal Poly-San Luis Obispo

Nilgun Sungar

About a decade ago, supported by a NSF-CCD grant, an undergraduate-level nonlinear dynamics course was developed at Cal Poly. The novel features of the course were the laboratory component and its interdisciplinary nature. A unique feature of the lab component is that the experiments utilize readily available equipment found in a typical undergraduate physics program. The inspiration for the course arose from the fact that the traditional undergraduate science and engineering curriculum emphasizes analytical solutions of differential equations which are not very useful in most real systems encountered by students later in life. The elegant geometrical methods and visualization techniques of nonlinear dynamics have not yet been incorporated into the undergraduate curriculum.

The nonlinear dynamics course is offered as an upper division elective course to all science and engineering majors. So far it has been offered 6 times and taken by around 100 students, 55% of which were physics majors and the rest mostly from a variety of engineering departments. The course has a three 1 hour lecture component and a three hour lab component offered over a 10 week quarter. The lectures emphasize geometrical methods and visualization tools such as phase space, fixed points, bifurcations, limit cycles and attractors. The textbook used for the course is *Nonlinear Dynamics and Chaos* by S. Strogatz which is at the appropriate level and has an interdisciplinary approach. The experiments that were developed at Cal Poly follow the lecture material closely and teach data acquisition, data display, and analysis techniques such as power spectra, Poincare sections and return maps on a variety of systems from different fields. The experiments can be downloaded at the web site www.calpoly.edu/~nsungar/nonlinear.html and more information on the course can be found in *AJP* 69 (5), 591-597 (2001). A major feature of the lab component is that after doing prescribed experiments for seven weeks, students are required to complete a three week project on a system of their choice. Initially, the goal of the project component was to allow students apply their knowledge on a system in their field. Over the many offerings of the course, it was also realized that the project component provides a unique experience on an open-ended problem and the students show great enthusiasm and effort. Two weeks before they start the project, a collection of literature on experiments (including computational experiments) on nonlinear systems are made available to the students. They are also encouraged to talk to professors in their own departments and do a literature search. Another possibility that is presented to the students is to expand on and do a more sophisticated analysis of one of the prescribed experiments done earlier in the quarter. Of all the students who took the course, only 22% chose to expand one of the prescribed experiments. It was also noted that 38% of the projects were computational and the rest experimental. The projects involve construction of new equipment, assembling of equipment and programming and can be open ended. Students have to choose, plan, perform and report with minimum supervision from faculty. It must be recognized however that the supervision of the projects is faculty-intensive. All faculty involved in the course (five of us in the physics department), even those who are not teaching that quarter participate in supervising projects. In addition, several technicians in the physics department assist students in finding or ordering equipment for their projects. The students are expected to write a formal report on their project. About 50% of the students actually bring their project to a successful completion. However, almost all students show great effort and creativity and learn to deal with problems that arise in designing and conducting an experiment. The textbook which has examples from many disciplines also provides ideas for projects. For example, one of the students has built the chaotic waterwheel described in the textbook while others attempted to build the bead on a tilted wire example. We have also noticed that there are several “popular” projects, taken on by multiple students. These include the double pendulum, the chaotic bouncing ball, the buckling beam and construction of chaotic electronic circuits. In a few cases, physics majors, after taking the course have done research with faculty on projects related to nonlinear dynamics.

In summary, we believe that such a course incorporating the geometrical methods for dynamical systems represented by differential equations provide valuable addition to student’s education. The project component highly motivates the students and allows them to work on an open ended problem and apply the techniques they learn in class. Although the project component is intensive in faculty and technician time, the equipment required to build such a course is readily available in most physics departments and, if not, could be acquired at low cost. A possible improvement would be to allow longer time for the projects which could easily be done at institutions following a semester system.

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Using concept building laboratories in optics to improve student research skills

Mark F. Masters

Much of my research (atomic and molecular spectroscopy) involves the use of simple geometric optics to set up light collection systems. Unfortunately, students involved in my research often have had to be re-taught basic optics. For example, students would assemble frustratingly poor optical systems based on stacked books and even, on one occasion, a Coke™ bottle. These students had, at a minimum, an exposure to optics in their introductory classes, but a disturbingly large fraction had actually completed an intermediate optics class and its associated laboratory. Clearly, the students had not fully integrated their understanding of optics.

Optics is a very important aspect of the physics curriculum. Typical topics include basic geometric optics and physical optics. If one considers the traditional introductory physics class as part of a two semester sequence, all topics within optics might be covered in approximately four or five weeks. The traditional introductory laboratory might allow for five demonstrations or as in our case of single topic laboratories (DC circuits), not covered at all. This is simply not enough time for students to achieve any understanding of this topic. The intermediate optics class is typically built upon this weak foundation. It rapidly reviews the optics that the students should have mastered in the introductory class and then gives the students a highly mathematical representation of the physics. The laboratory is often a sequence of guided demonstrations. Unfortunately, our evidence indicated that the students were not learning what was intended. To correct this situation we started a complete revision of our optics course and associated laboratory to assist the students in constructing an “optics framework”.

We started the revisions with consideration that the students were almost always engaged in “answer-making” rather than “sense-making.” “Answer-making” is the ability to come up with some form of an answer without the ability to explain how that answer is reasonable and how that answer makes sense. It typically involves “plug-n-chug” types of problems. “Sense-making” is coming up with the explanations and requires understanding of the subject at hand. “Sense-making” requires a deeper understanding of the material.

With the goal of producing “sense-makers”, the lecture component of our optics class was changed so that it employed interactive engagement and used tutorials to build understanding and mathematical sophistication for the students. However, providing hands-on activities in the laboratory in such a way that the students were not simply following directions but discovering the optics was deemed critical. As such, we expended significant effort in revising these laboratories such that the students would discover the physics rather than simply be told. The laboratories were designed so that later laboratories built upon the earlier experiences so that students could not follow a “memorize and dump” procedure. Unfortunately, this laboratory format significantly curtails the number of topics that can be explored through laboratory. For this reason our laboratories concentrate on geometrical optics and polarization with the bulk of the laboratories on geometrical optics. Physical optics was not included because we found that meaningful investigations would exceed the time we had available and simpler physical optics investigations devolved into instruction based rather than discovery. The laboratories are described in Ref [1] and are available on the web [2].

Assessment

As with any investigation, it is important to assess the results to determine whether the “experiment” is successful. For this project, we examined two cohorts of students and we use two methods to collect and evaluate the data. The first data is from embedded questions within the laboratories. We look at the student ability to answer the questions (“answer-making”) and their ability to explain their answers (“sense-making”). This method was used for both cohorts. The second set of data was used only for the second cohort. It involved administering a preliminary version of an optics concept assessment that we have been developing [3] as a pre-post-test and examining student improvement.

Using the pre- post-test for the second cohort, we found that students who took the optics laboratory (physics majors) demonstrated significantly greater improvement than those who did not (engineering majors). This indicates that the laboratory makes a difference in student learning of optics.

Using the embedded questions we found that as the semester progressed the students in the first cohort demonstrated a marked improvement in the quality of their explanations. The students in this cohort started an emphasis on answer-making with poor or novice explanations, but by the end of the semester, the explanations were approaching what we classified as professional. For the second cohort we also found improvement in the progress from answer making to sense-making. However, it was not as significant as for the first cohort. So why was that?

For years we have been asking the students about their introductory laboratory experience when they come to our modern physics laboratory. We ask this question because we do not have department-wide laboratories. Some of the laboratories are discovery based and engage the students while others are much more cookbook. When we compare the introductory laboratory experiences of the first cohort with the second, we find that the first cohort was provided with the former while the latter were given largely cookbook type experiences. The introductory laboratory sets the “stage” for student expectations in later advanced laboratories. These expectations are very difficult or even impossible to change in later lab experiences.

We have also observed that class format has a significant impact on how the students approach laboratory and student performance in the laboratory. Given open-ended, discovery based laboratories, students in a traditional lecture class will struggle much more significantly than the students with an active learning class. The skill of inquiry must be developed and nurtured in both class and laboratory.

What are labs for and preparing students for research

These laboratories have alleviated some of the problems of bringing students into the research laboratory. When they enter (after taking the optics class), we do not need to teach them basic optics to get them started. At the same time, there is the lack of exposure of the students to physical optics. This problem is alleviated by a class (and laboratory) on physical optics and interferometry.

The larger question is: what are we (as physicists) trying to achieve through laboratory. The data we have examined indicate that laboratory and class are coupled; that the introductory laboratory format is of critical importance to later laboratory experiences; and that laboratory can have a significant impact on student learning. I believe that laboratories must emphasize inquiry and discovery. We cannot provide the students with simple follow-the-directions experiences and then expect the students to suddenly become, and have the skills to be, inquisitive. Laboratories must model what we expect of the students.

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New Photon Labs Infuse Energy and Content into Advanced Laboratories and Curriculum

Enrique J. Galvez

Introduction

The last ten years have seen the development of new advanced physics laboratories that emphasize a new array of topics not touched by previous laboratories: fundamentals of quantum mechanics. The labs involve quantum optics experiments. They use a modern source of light brought in by technological advances and current research in quantum computing: correlated photon pairs. The experiments are table-top and do not require an optical table or large and expensive lasers. They incorporate a number of techniques both in terms of optics hardware (alignment of optical beams and interferometers) and electronics (photon counting and coincidence timing), but their real strength is in the physics they convey. In fact, the physics of the experiments is so compelling that the labs have been adopted at a number of levels, from introductory, to intermediate, to advanced, and as a laboratory component for a quantum mechanics course (see Ref. 1 and references therein).

In addition, the experiments address fundamental topics of quantum mechanics that are sometimes sidestepped in instruction in favor of more mechanical treatments of quantum mechanics. In experiments performed one photon at a time the physics of the experiments concentrates on the quantum mechanics of a single quantum, precisely the type of approach used in introducing the principles of quantum mechanics. The experiments can touch on misconceptions about what photons are, wave-particle duality riddles, and on more fundamental tenets of quantum mechanics such as non-realism and non-locality. Finally, in an era very enthusiastic about quantum information and the prospects of quantum computing, the experiments can provide non-physics beginners a more vivid demonstration of quantum superposition, the fundamental pillar of this new technology.

There are two types of experiments that can be performed with this apparatus. Both use a unique light source whose output is a pair of photons. These photons can be used in two ways. In a first way, one photon does something, and is "heralded" by its partner. That is, one partner announces the presence of the other in the apparatus. Each experiment then requires that both photons be detected. Since both photons are created simultaneously then coincidence detection is part of the data acquisition apparatus. This heralded-photon setup is critical in making this source quantum mechanical. As such the source of light is non-classical. An attenuated source of light (e.g., a laser) behaves as a "classical" source, and so all experiments done with it can be explained by a classical treatment. A non-classical source requires a quantum mechanical explanation. Below we describe an experiment that distinguishes between the two.

A second way of using the source treats both photons of a pair as equals. Both photons are born together and thus carry correlations that can be shown to be quantum mechanical, and in many situations they behave as one, and are thus called "biphotons." The ultimate correlation of biphotons is the entangled state, which can be straight-forwardly produced![2] Various implementations of this method result in undergraduates doing a measurement of a violation of Bell inequalities in one afternoon's laboratory.

In this article I give an overview of the general apparatus used in these experiments and the types of experiments that have been developed for undergraduates.

Apparatus

The source of light relies on the process of spontaneous parametric down conversion; it consists of the generation of two photons from one pump photon. Energy and momentum are conserved in the process, so if we consider the pair to have the same energy then they have a wavelength that is twice the wavelength of the original (pump) photon. This puts certain restrictions on the wavelength of the pump beam, because the photon pairs have to be detected individually with reasonable efficiency. For this reason, inexpensive photomultipliers are unfortunately not suitable. These are efficient in the mid visible range or lower wavelengths, but then they would require ultraviolet pump sources. The best compromise today is avalanche photodiodes, which have reasonable detection efficiency in the near infra-red. With these detectors the pump photons have a wavelength in the blue wavelength range of the visible.

Today the source is quite inexpensive because of the proliferation of Bluray video players, which carry a 405-nm GaN diode laser. A number of web sources already sell intense blue diode laser pointers (unsafe to use as such) for as low as $20! With a little bit of technology these diode lasers can be made temperature and current stable and be suitable for research well beyond undergraduate laboratories. The parametric down-conversion to low energy pairs is done with a non-linear crystal that costs about $500. The source has a low efficiency: 10^{-8}, and after wavelength selection filtering and other losses, the final efficiency can be as low as 10^{-10}. However, with a 20 mW pump source delivering 4 x 10^{16} photons per second, we still have plenty of pairs for photon counting experiments. More details on this source can be found in Ref. 4.

The photons then go through an apparatus that has optical hardware. These involve interferometer components (beam splitters and mirrors), polarizing optics (waveplates and polarizers), and detection components (filters and optical fibers). Our prototypes mount all of this hardware on a 2x5 ft optical breadboard. The components can be taken from equipment at hand. The only technique to avoid troubles with interference is to keep the optical beams low on the table and the size interferometers as small as possible. Since the light is broad-band the interferometer needs to be carefully aligned.[4] Figure 1 shows a schematic accompanied with photos of our setup at Colgate University. More details of the hardware, setups and methods are given in our website.[5]

The detectors are currently the expensive component of the apparatus, at about $8000 for two detectors. A group of members of the physics education community has been in contact with vendors of these detectors to make more inexpensive options, so there is hope that these prices will come down. The detectors produce 5-volt square (TTL) pulses per detected photon. The pulses have to then go through a system of pulse electronics for pulse counting and coincidence detection. This can be accomplished by either using standard NIM modules[4] or integrated interface cards.[6]

Experiments

As mentioned earlier we have two types of experiments: heralded-photon experiments and biphoton experiments. In heralded-photon experiments we send one photon directly to a detector, and the other one through an interferometer and then to a detector. There are a number of experiments that can be done with this setup (the same as the one in Fig. 1). In a first experiment we just send the light through the interferometer. The probability that the photon passes through the interferometer is $\frac{1}{2}(1 + \cos \delta)$, where δ is the phase due to the path length difference. The data gives lots of counts per second when the phase is a multiple of 2π and a minimum near zero when the phase is an odd multiple of π. One can understand this experiment as a single quantum (the photon) leaving the interferometer in a superposition of having traveled both paths. It is a fundamental principle of quantum mechanics, and what distinguishes it from classical mechanics. The discrete nature of the counts underscores Dirac's famous quote that in going through an interferometer each photon interferes with itself and not with other photons. The mystery is augmented by putting a beam splitter after the interferometer, which does not show that the photons split at that splitter.

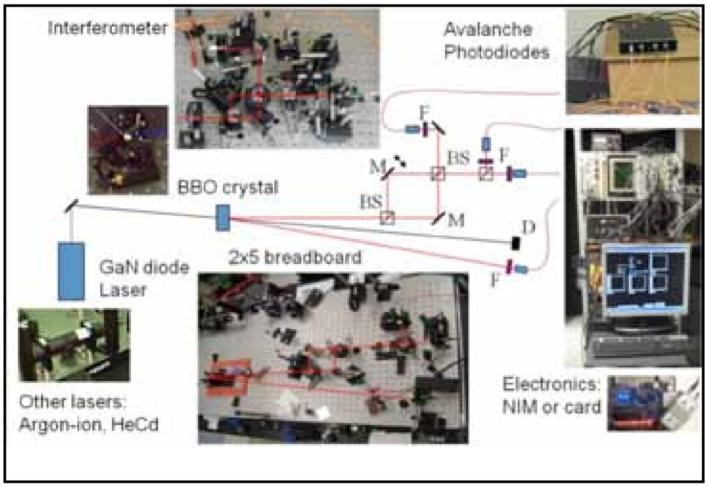

Figure 1. Layout of the apparatus. The interferometer has non-polarizing beam splitters (BS), mirrors (M). Photons are channeled to detectors via optical fibers preceded by filters (F).

A popular extension of the interferometer is the quantum eraser, whereby using polarization optics we can eliminate the interference. This setup can be used to underscore a more conceptual aspect of superposition: that it exists provided that the paths leading to it are indistinguishable. Conversely, when the paths are distinguishable superposition (and interference) disappear. Manipulation of the polarization allows making the path information distinguishable or not. The "eraser" is a polarizer placed after the interferometer that, in the case when the path information is distinguishable, it erases the distinguishing information. We offer a laboratory experience on the quantum eraser to the first-year students that take our course on introductory modern physics (the first course in our physics sequence).[7] The data that they take is divided into three sections, as shown in Fig. 2. In a first section the paths of the interferometer are distinguishable and so we see interference. The horizontal scale is proportional to the voltage sent to a device that changes the path length of one of the arms of the interferometer. It can be seen that coincident photon counts oscillate between maxima and minima, one photon at a time. In a middle portion the paths are made distinguishable by rotating the polarization of the light in one of the arms, making the paths distinguishable. The data is flat showing no interference (the probability is ½ in this section). In a third section we put a polarizer after the interferometer with its axis such that the polarizations of the two arms project equally. Past the polarizer the light has the same polarization regardless which path the light took. As a consequence, the light contains no path information; the polarizer erased the path information The data for this section shows oscillations again. The detection probability is $\frac{1}{4}(1 + \cos\delta)$.

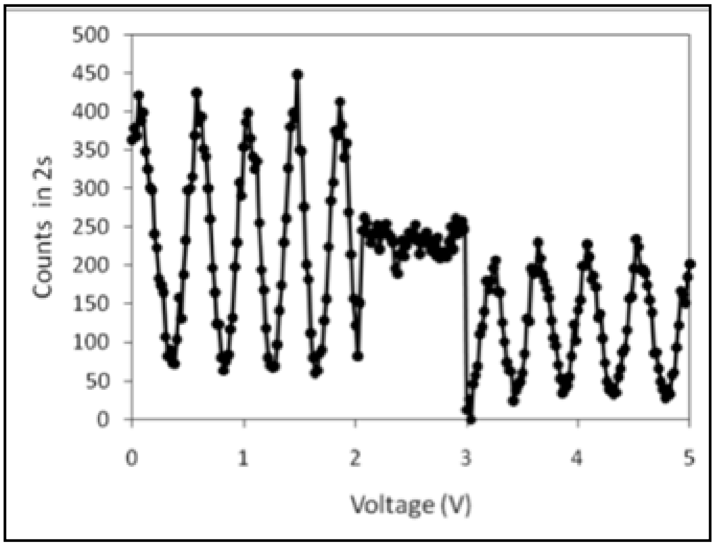

Figure 2. Data taken by first year students on the quantum eraser. It shows coincident counts of photons going through an interferometer and its heralding partner going directly to a detector. The horizontal scale is proportional to the voltage sent to a piezo electric that moved a mirror that changed the length of one of the arms. The three sections show the three conceptual components of the quantum eraser: the paths are indistinguishable (0-2 V), the paths are distinguishable (2-3 V) and the distinguishing information is erased by placing an optical component after the interferometer (3-5 V).

This exercise also underscores a more general view of interference, where one does not need to disturb the system to wash out the interference–a legacy of the Bohr-Einstein dialogues. Instead, the key concept is whether the path information is available or not.

An interesting variation of the eraser is the manipulation of the coherence length of the light.[5,8] One can view the coherence length as the length of the photon wave packet. Then interference would disappear when the path length difference of the interferometer is greater than the coherence length, a well known aspect of classical interferometry. However, in terms of photons one can understand this by picturing that interference disappears when the photons arrive to the detector at measurably distinct times that depend on the path that they took in the interferometer. The information can be erased by increasing the coherence length to values greater than the path-length difference via filters put before either detector.

As mentioned earlier, all of these experiments can be combined with sending the signal photon to a beam splitter and putting detectors at both output ports of the beam splitter. This allows doing a recreation of the Hanbury-Brown-Twiss test and a measurement of the degree of second-order correlation.[9] This test basically amounts to showing that a photon exists because it does not split like a wave at a beam splitter into two half photons of the same wavelength as the incident photon, something predicted for a classical wave.

There are a number of interesting experiments that can be done with biphotons. We have done much work in developing experiments where two collinear photons go through an interferometer, producing an interesting pattern of interference that involves multiple paths.[1] The experiments can also be used to show that some of the interference is due to the bosonic symmetry of the photon wavefunction.[5]

Finally, the ultimate experiment is the one that can be used to prepare photon pairs in polarization entangled states. One can use this setup to understand the difference between entangled and mixed states (the realistic view).[1] A culmination of this is a measurement of a violation of a Bell inequality.[3] The setup is now well developed, and can be used to test other interesting variations of the inequalities.[10] All of these experiments test students' understanding of the quantum mechanical algebra but also of its fundamental philosophical underpinnings.

Conclusion

In summary, I presented here a brief description of a relatively new set of experiments that open the door for new laboratory explorations at the undergraduate level. Due to their cost the experiments are slowly being adopted, but in time with the availability of lower cost components, these experiments could become a staple of modern advanced laboratories.

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Using the "Black Box" Approach to Enliven Introductory Physics Labs

Joe Amato and Colleagues

I. Introduction

It is well established that when undergraduates are exposed to research or research-like activities, they are strongly motivated to continue their studies in physics or astronomy. At many schools, juniors and seniors have ample opportunity to participate meaningfully in publishable research, often in addition to enrolling in advanced lab courses which expose students to a research-like setting. But attrition is most serious among *beginning* students, and so it is vitally important to inspire and encourage students who are enrolled in our challenging introductory courses. One way to do this is to replace the lab exercises that are customarily used in our introductory courses with ones that, in some sense, expose beginning students to the *spirit* and challenge of scientific research.

This approach was suggested in 1988 by Anthony French [1], who deplored the typical lab exercise as tending to "reinforce this picture of physics as a cut-and-dried, finished, essentially dead subject. Experiments to verify that momentum is approximately conserved, or that g has the value that every student already knows it to have, are scarcely calculated to inspire curiosity about the way the world works." He then proposed an alternative approach: "I believe that much could be done to reformulate some of our simple laboratory exercises so that they become genuine questions with the answer not known to the student (or, perhaps, to anyone) in advance..." We have adopted this "black box" approach at Colgate, and believe it to be an unqualified success. In the following sections, we present some examples of "black box" labs that are presently employed in our introductory physics sequence.

II. Black Box Labs for Introductory Mechanics

It can be exceedingly simple and inexpensive to modify existing labs, or develop new ones, to incorporate the black box approach. For example, one of the first labs our students encounter in the calculus-based mechanics course addresses measurement uncertainty and its propagation. Working in pairs, students are given a brass cylinder (each cylinder differs from the others, with length and diameter ≈ 2 cm) that has been asymmetrically etched in acid so that its dimensions vary roughly by ± 0.01 cm. Treating this variation as uncertainty, they are asked to determine the cylinder's volume $V \pm \Delta V$. The instructor then measures its mass, using a digital scale, and the students then calculate the cylinder's density. The "black box" aspect comes next: students are given a second cylinder made from the same material (brass), and are asked to determine its volume and predict its mass $M \pm \Delta M$. When they are satisfied with their calculations, they present their second cylinder to the instructor for weighing. Their grade depends on agreement between their calculated mass and the measurement. If they agree, and their uncertainty calculations are correct, they receive an "A." If they do not agree–on the first try–they receive a lower grade. The moment of measurement is filled with trepidation, followed (usually) by elation, but sometimes by disappointment. It is both exciting and educational.

This approach to lab work is invariably effective: students are presented with a single well-defined task, and it is their responsibility to complete it successfully. (Nearly all groups are successful.) Although there is no concealed component involved, the mass of the second cylinder is unknown *a priori*, so that careful measurements and calculations are clearly essential and need no further motivation.

More sophisticated black box apparatus can be constructed using very simple materials. Figure 1 illustrates a versatile apparatus that has worked quite well for us. A long PVC pipe (3 inch diameter, 4–5 feet long), fitted with end caps, stands vertically on the floor and is rigidly clamped to a lab bench. There is a hole in the top cap, through which a string is attached to the apparatus hidden within the tube. The string passes over two pulleys to a hanging mass *M,* whose vertical position h is measured with a meter stick. By measuring (and plotting) *h(M)*, students are challenged to identify the contents of the tube.

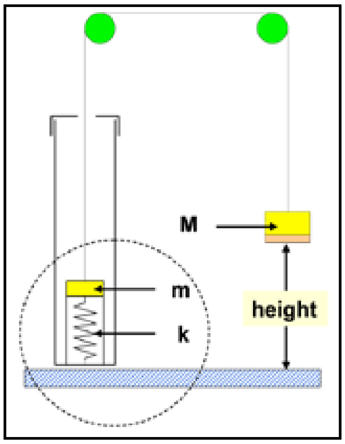

Figure 1

In the example shown, the hidden contents consist of a cylindrical disk of mass *m* attached to a fixed base plate by a spring of stiffness *k*. The disk is seated within a short plastic cylinder so that, at the lowest position of the mass, the spring is still stretched by a distance x_0. This arrangement is carefully described to the students, but they must find a way to determine values for *m* and *k*. Briefly, the spring stiffness is determined by the slope of *h(M)*, and the unknown mass m is then found by measuring the period of oscillation of the apparatus *(M+m)*.

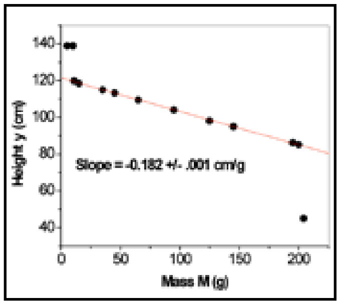

Figure 2

In a more challenging follow-on experiment, the mass-spring apparatus is removed from the PVC tube, which is then filled half way with water. A slender polystyrene rod (2.5 cm diameter, 30 cm long) is attached to the string and lowered into the water. No description of the tube's contents are provided to students, who are asked to construct a physical model of the contents that is consistent with their *h(M)* data. This

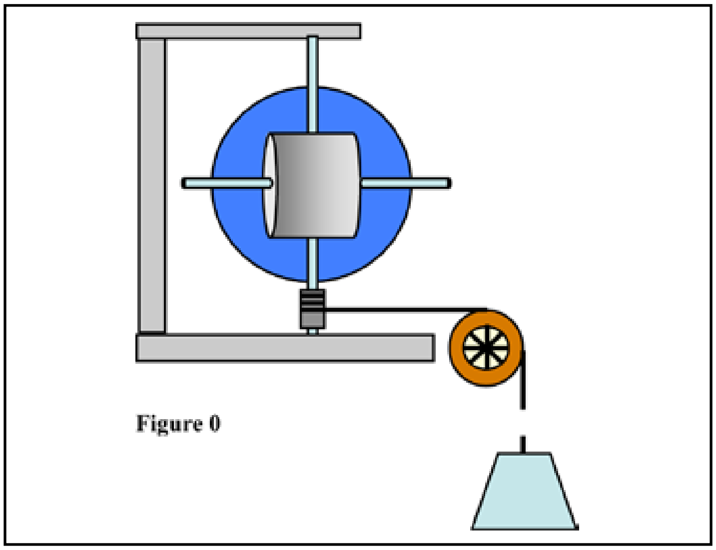
Figure 0

data (Figure 2) is more complicated than in the above case: only when the rod is partially submerged (between M_{in} and M_{out} on Figure 2) does the height vary linearly with mass M. Indeed, because the specific gravity of polystyrene is 1.05, the force needed to extract the rod from the water varies from near-zero to the full weight of the rod, mimicking a spring force convincingly. The abrupt changes in behavior at M_{in} and M_{out} cannot be ignored, however, and it is a challenging assignment to explain the entire data set. In this exercise, we allow student groups to collaborate, and give special "recognition" to the first group to "publish" correct results. Of course, there is more than one model that is consistent with the data (i.e., two masses attached with a spring and length of string), and we award full credit for models that "work" correctly. In many ways, this is akin to how real research is conducted.

The "hidden object" strategy is limited only by the instructor's imagination, and can be employed to exercise students' understanding of a broad variety of physical concepts. For our final lab experiment in Mechanics, a simply-shaped object such as a cylinder, disk, or square bar is suspended by lightweight axles that pass through the object's center of mass along its principal axes of rotation. The object is concealed within a thin opaque spherical shell with the axles protruding (Figure 3) so that they can be inserted into low friction bearings for spinning the object. String is wound around the lower bearing, and passes over a pulley to a hanging mass. When the mass is released, the rotational acceleration of the object is recorded and used to find the moment of inertia of the assembly about each of the three axes of rotation. These data, along with the mass of the object, are used to determine the size and shape of the object. This is a challenging project, and requires careful measurements and error-free calculations. Each student works on a unique object, so that collaboration is not possible. Ideally, even the instructor does not know what is inside a particular shell.

At the GRC, we demonstrated a much simpler and less expensive version of this apparatus. Rather than spinning the object, it is hung from a stainless steel torsion wire and its period of oscillation is found. The torsion wire is calibrated using a known (visible) object such as a disk. With careful measurements, the dimensions of the hidden object can be determined to within 1 %. Unambiguous results are easily obtained, and the exercise can be very satisfying for students. We are careful to point out that this exercise is akin to, say, a nuclear physics experiment wherein the shape of a nucleus is determined by studying its rotational properties.

III. Black Box Labs for Modern Physics

The black box strategy, of course, is not limited to mechanics. Although we have not yet done so, it is easy to imagine black box exercises in electromagnetism, fluids, and thermodynamics. We have, however, designed and deployed two black box experiments for modern physics. In the first experiment [2], a glass bell jar containing a pure gas such as N2 is evacuated through a tiny orifice (diameter = 400 μm) by an inexpensive homemade sorption pump. By measuring the gas pressure vs. time during the evacuation period (about 15 minutes), the average speed of the gas molecules (≈ 500 m/s) can be determined to within a few percent. Depending on the context of the experiment, this can be the goal of the exercise; better yet, students can be asked to use their calculated speed to identify the gas. The second experiment [3] employs a novel microwave Bragg scattering apparatus, using a rotating "crystal" array of metal rods, to mimic x-ray diffraction and discover the meaning of Miller indices. The method yields data that are sufficiently accurate so that the spacing and orientation of a shrouded (unknown) crystal can be determined easily. The apparatus for these two experiments are somewhat more complicated than that described for the mechanics labs, and we refer the reader to the published accounts for full details.

IV. Summary

Black box labs are an effective way to instill the spirit of research into the introductory curriculum. Properly designed, they can "inspire curiosity about the way the world works." They can be easy and inexpensive to implement, challenging and fun for students, and enjoyable to teach as well. They are suitable for reinforcing many, but not all, topics encountered in the introductory curriculum. In 1989, Alfred Romer [4] pointed out that lab exercises and apparatus are constrained by available time, relevance to the curriculum, significance of the exercise, and the probability of student success. Used with discretion, the black box strategy can be a valuable way to enhance and enliven the introductory physics curriculum.

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Go Forth and Measure

Matthew J. Lang

Go forth and measure, GF, is a capstone lab performed individually by students enrolled in mechanical engineering's core measurement and instrumentation course, 2.671. The GF project spans the whole semester beginning with a getting-to-know-your-sensor exercise and ending with a departmental wide poster session and project paper. The individualized projects require multiple one-on-one meetings with students. Project topics are vetted by instructors but chosen by students. The topics are unique and creative, frequently relating to a personal passion, interest, curiosity or hobby. Students don't see their projects as boring, and as a result, a student's ability to put into practice the course material is substantially enhanced. Many projects lead directly into a senior thesis and get students noticed and recruited to undergraduate research.

The GF project has expanded over the years and progresses semester long through a series of milestone goals representing 28% of the overall course grade. Students initially are given a lecture on SI units followed by snippets of past projects that showcase an array of sensors, many of which are from Vernier, that measure acceleration, temperature, pH, sound, velocity, force, light level, pressure and images at high speed. Milestone 1 is to propose a study and define one or more sensors that will be required for use in the measurement, including documentation of sensor resolution and measurement range specifications. (This milestone is due week 2, representing 2% of the course grade.) Here the project is reviewed, including for safety, allowing for initial feedback and discussion of the idea. The scope of the project is also discussed as students can frequently be overly ambitious, planning to measure many parameters or perform multiple measurements simultaneously. Some projects span many weeks and require careful initial planning. Milestone 2, (week 5, 4%), requires an actual measurement of any kind of data relating to the project. By this point, students have received instruction on how to use the AtoD logging measurement modules, (we use Labpro units,) which are signed out along with appropriate sensors. Students are now practiced at making the type of measurement needed for their project. Here students again review the scope of the project and more carefully plan their full study.

Milestone 3 requires executing the full study and submitting a rough draft of a project paper, (week 8, 6%). To do this, students go deep into their projects collecting the lion share of the data. Students necessarily begin their analysis and modeling. Draft papers are reviewed by faculty for technical content and revised with formal writing instruction. While working on their paper revisions, students prepare a draft poster and meet with their lab section for a practice poster session, Milestone 4 (week 11, 4%). The poster is revised and students present their projects at a departmental wide poster session, Milestone 5 (week 12/13, 4%). Final project papers, Milestone 6, are due at the end of term, (week 14, 8%).

A number of assets are required, in particular the enthusiasm, passion and organization from our laboratory instructor. Our term enrollments are 70+ students distributed among 5 or more sections. Faculty also need to be engaged and provide constant feedback along the way to maintain project progress. The lab is physically equipped with enough AtoD modules for each student and a warehouse of sensors and parts for building what is needed to achieve project goals. Additional resources, such as student access to advanced measurements including high speed cameras, wind tunnels and general equipment found in institute or departmental labs, can substantially enhance the ranges of projects students can approach. Small funds are also available for purchasing additional sensors that are not part of the lab inventory. Despite these considerable assets, many projects are executed with everyday devices such as cell phones and low cost components that the students simply wire up themselves. Students energize their projects with people power, heavily recruiting their colleagues as subjects and assistants.

Launching a fully loaded GF project from scratch can be difficult. Rather, a robust GF project can be built on over the years. Initially, our GF project went only to the point of requiring a single measurement and a one page abstract. One might initiate a GF project by working only through Milestone 2, and ramping up after an inventory of sensors and know-how has been amassed. One can also reduce the scope of the GF project by only requiring a final poster or a paper but not both. A GF paper is valuable for formal writing instruction due to the uniqueness of the topics, while a GF poster allows students to practice communication and presentation skills.

From the faculty perspective, the GF project has been rewarding to teach. Students put a great deal of effort into the projects, with some studies even approaching original research articles. Students can express their creativity while learning how to design and optimize a study. Students apply lessons learned in the core labs and lectures to achieve many more projects than one faculty team could develop each term. Our standard core labs include pressure determination in a soda can, interferometry, stress strain, fluid flow, muscle force, motor output, electro-mechanical systems, and sound speed. Adding to this curriculum are "n" student implemented studies, projects that are interesting, fun, contemporary and constantly being refreshed. For example my Fall 2009 project topics included concentrating solar power, rabbit nutrition, drafting by swimmers, impact of soccer ball heading, wall flip dynamics of free-runners, calf muscle stimulation in runners/walkers, spin on table tennis serves, soccer kick dynamics, angular velocity in swing dance moves, delay in campus bus vs. time/day of week/ weather, building height determination, wine glass frequencies, kitchen pot frequencies, harmonics of cylindrical vs. conical wind instruments, non-dimensional leg kinematics and wind speed around buildings.

I would like to acknowledge my fellow instructors, Ian Hunter and John Leonard. I am especially grateful for the special dedication of Dr. Barbara Hughey and former students enrolled in MIT's 2.671, Measurement and Instrumentation course.

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Integrating Experiments and Computer Simulations To Promote Learning

Fred Goldberg

Introduction

Over the past decade several co-authors and I have been involved in the development of three physics and physical science curricula, one for middle school students [1] and two for college students, especially prospective elementary teachers [2,3]. Each curriculum was designed to guide students through a sequence of laboratory experiments and computer simulations to test their ideas about phenomena, and to provide the opportunity for students to consider both the laboratory and simulator-based evidence in small group and whole class discussions.

In writing the curricula we did pay careful attention to the difference between the hands-on laboratory experiments (including the use of probeware) and the computer simulations that modeled physical experiments. We viewed learning science as making sense of physical phenomena (through observations with hands-on materials) and making sense of models of phenomena (through observations with computer simulations). The evidence from laboratory experiments help students develop models that explain phenomenon. They use computer-simulation evidence to develop models of someone else's (the programmer's) model of a phenomenon. Although there are epistemological differences between these two ways of constructing knowledge, we found that students rarely were concerned about the difference; they usually saw the results of both as equally believable and equally helpful in developing their own ideas.

Among the various issues we had in mind as we designed the activities for these curricula were these two questions. How can a sequence of experiments guide development of ideas or models? How can computer simulations complement what students learn from laboratory experiments? Below I describe in some detail an example from the *Physics and Everyday Thinking* curriculum, or *PET*, [2] to illustrate one way that we addressed these questions.

An Example: Students Developing a Model of Magnetism

One of the six units comprising the *Physics and Everyday Thinking Curriculum* focuses on providing the opportunity for students to develop a model for magnetism (In this class students take primary responsibility for developing models, using observational evidence as the arbiter of model validity; the instructor only plays a supportive and facilitative role.) The unit consists of three activities and a homework assignment that engage students in the process of constructing, testing and revising models to explain and predict observations of some magnetism phenomena, a fourth activity where students apply their final model to explain other magnetism phenomena, and a fifth activity and two homework assignments that focus on the history and nature of science and the nature of learning. Each of the magnetism activities takes about 2 hours to complete. Here I will describe just the first three activities and the homework following the third activity. My purpose is to show how the sequence of laboratory experiments and computer simulations help promote the development of a model of magnetism that can both explain and predict a certain range of phenomena. The magnetism activities were adapted from a previous curriculum development project.[4]

The purpose of the first magnetism activity is for students to make a set of observations involving magnets and nails to establish a base of evidence that they could draw on to support their construction of a model for magnetism. Students use bar magnets and nails to explore the interactions between two magnetized nails and between a magnetized and unmagnetized nail. To magnetize a nail, the student holds one end of the bar magnet (either the North Pole or South Pole) against one end of the nail and slides the magnet from that end to the other end. She then lifts the bar magnet and repeats the process several times, always rubbing the nail in the same direction. (At first, students are told to do it this way so the class would start with a common set of observations. Later, after students develop a model, they can understand why they need to rub it in only one direction.) A nail prepared in this way is referred to in the curriculum as a *rubbed* nail. To test the interactions between nails, the student places a nail (either rubbed or unrubbed) on a small, flat piece of Styrofoam floating in water in an aluminum pie tin. She then brings the head end of a rubbed nail near the head end of the floating nail and then near the point end of the floating nail and observes what happens. After making several similar observations with rubbed and unrubbed nails and with different ends of nails, students conclude that: (1) each end of a rubbed nail attracts each end of an unrubbed nail; and (2) each end of a rubbed nail attracts one end of a rubbed nail and repels the other end. Thus a rubbed nail is seen as being *two-ended*, in the sense that each end behaves differently when near one end of another rubbed nail. As part of the same activity, students also notice that a floating rubbed nail, when spun on the Styrofoam floater and left by itself, would always end up oriented with one end pointing toward the geographical north. That end is defined as the North Pole of the rubbed nail; the other end is the South Pole. Students then develop a strategy for how to rub the nail so that a specific end would become a North Pole.

The second magnetism activity focuses on constructing, testing and revising models. Students start the activity by proposing a model for what happens in a nail when it is rubbed that could explain their observations from the first activity. Each group in the class then shares its model with the rest of the class. (Whole class discussions are an important part of the PET pedagogy, since it is in these settings where students both need to clarify their own thinking in order to share their ideas with others, and also become aware of what other groups are thinking.) Almost all the groups in the class propose what we call a 'separation' model. In this model there are two types of entities, either plusses and minuses, or norths and souths, which are arranged randomly throughout the unrubbed nail. The act of rubbing in one direction with a magnet causes one type of entity to move towards one end of the nail, and the other type of entity to move towards the other end of the nail. Figure 1 shows a representative model of this type presented by one of the groups in the class. Students justify how this separation model can account for the interaction between two rubbed nails in terms of opposite entities attracting and like entities repelling. [Most students actually use plusses (+) and minuses (-) as the entities, but some, like the group whose model is shown in Figure 1, use norths (N) and souths (S). Students often refer to the entities as 'charges,' regardless of whether they are represented as +'s and –'s or as N's and S's. Later in the unit the class considers evidence for whether magnetic phenomena is the same as or different from electrostatic phenomena, agree that they are different, and thus it would not be appropriate to use plusses and minuses to explain magnetic phenomena.]

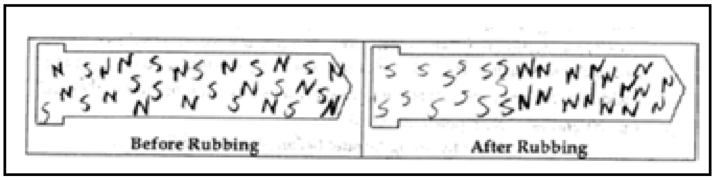

Figure 1. An initial student model for what she imagines is the type and arrangement of entities inside a nail, both before and after it is rubbed with a magnet.

In the next part of the second activity students are asked to use their model to make a prediction: What would happen if you cut the nail in half? When arguing from their separation model, students explain that since each half of the original nail will contain only one type of entity, the tip of a rubbed nail should attract both ends of one of the half-nails and repel both ends of the other half-nail. See Figure 2.

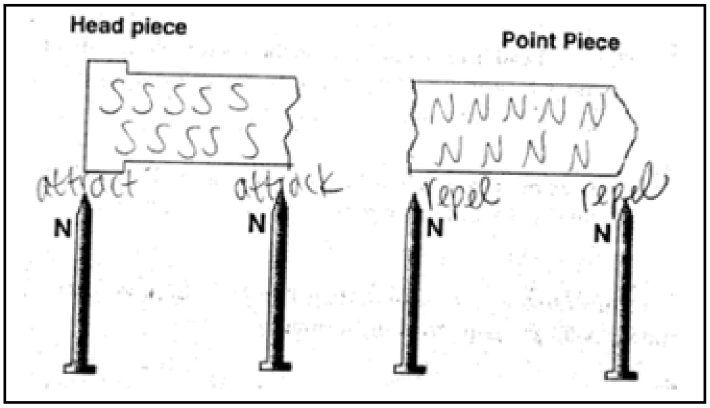

Figure 2. A prediction for what might happen if a magnetized nail is cut in half and then another magnetized nail is brought near each end of each piece.

When they actually do the experiment, they observe that contrary to their model's prediction, each end of the rubbed nail attracts one end of each half-nail and repels the other end. This suggests that each half-nail is two-ended; that is, it behaves like a rubbed nail. Students then try to revise their model to account for this new evidence. Most try to modify their original separation model for the rubbed nail by including a mixture of both entities in the middle. See Figure 3. When asked to use their model to account for the new evidence, students tend to say something like: *when the nail is cut, the mixed charges in the middle separate, making each half have two different poles.* However, they do not provide any mechanism for why the mixed charges in the middle re-arrange themselves this way.

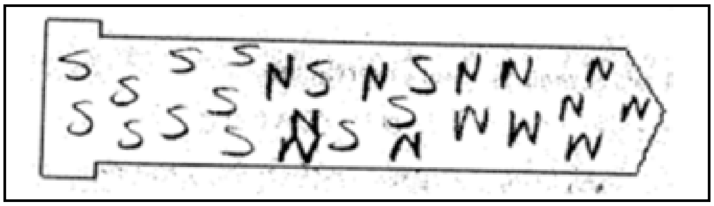

Figure 3. A student model for what she imagines is the arrangement of entities inside a magnetized nail before it is cut in half.

During the last part of the second activity the students cut their nail in either 1/3-2/3 pieces or 1/4-3/4 pieces and share results with the whole class. They observe (again) that each piece is still two-ended. To account for this additional evidence, students often make further revisions to their separation model. See Figure 4 for an example from the same group represented in Figure 3.

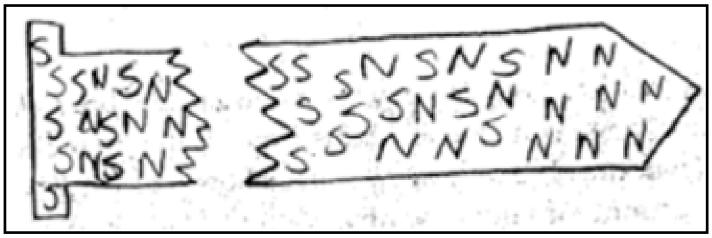

Figure 4. A student model for what she imagines is the arrangement of entities inside a magnetized nail after it is cut in 1/3-2/3 length pieces.

By the end of the second activity, all students are dissatisfied with their separation-type models, since by now they can generalize their observations: you could cut the nail anywhere along its length, and you'd still end up with two pieces that were each two-ended. They realize that a model that assumes the entities are separate N's and S's (or +'s and –'s), which move one way or the other during the rubbing of the nail, is not workable.

I have taught PET over ten times and the above description is pretty characteristic of what happens in the class. (Others who have taught PET have also confirmed a similar experience with their students.) So how is the class going to make progress? The third magnetism activity, where they work on further revisions to their model, was designed to provide a hint that helps most students. They are introduced to an analogy for the nail: a test tube filled with small iron filings. The students do some experiments with the test tube that are similar to what they had done with the nail. First they observe that each end of the test tube attracts each end of a floating rubbed nail. Thus, the test tube acts like an unrubbed nail. Then they rub a magnet over the test tube from one end to the other and observe that one end of the rubbed test tube attracts one end of the rubbed nail and repels the other end. Hence the rubbed test tube is two-ended; it behaves like a rubbed nail. Students are then encouraged to look closely at what happens to the filings when the magnet slides along

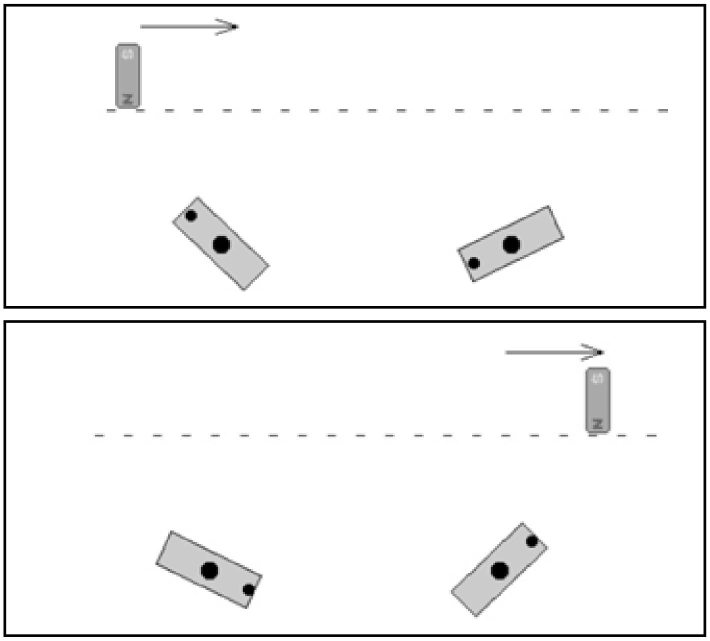

Figure 5. Screen shots from a computer simulation. The student drags a magnet across the screen and observes what happens to two other magnets that are constrained to rotate around pivot points through their centers.

the test tube. Some students, especially if they slide the magnet too slowly or if they don't pay careful attention claim that the magnet drags some filings to the end of the test tube; similar to what they had imagined happened in the nail, that the magnet drags one type of entity to the end of the nail (separation model). At this point in the activity, to help ensure students are *seeing* what the curriculum intended them to see, they run a computer simulation that models a magnet being moved near two other magnets that are each constrained to rotate around a fixed pivot. See Figure 5. They observe that as the magnet is dragged from one side of the screen to the other (along the dashed line in Figure 5), each of the lower two magnets rotates around its fixed point.[5]

They return to the test tube experiment and again look carefully at what happens to each iron filing as the magnet is dragged along the glass surface of the test tube. Assuming they don't move the magnet too slowly, they now 'see' that each filing is lifted up and then falls over on the other side as the magnet passes by. See Figures 6a and 6b. In this case, the computer simulation played an important role: it either guided them to make a critical observation, or it confirmed the original observation they had made.

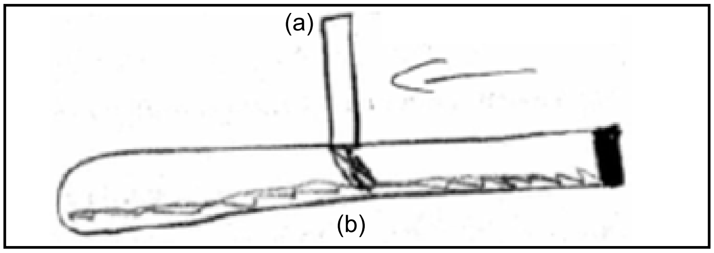

Figure 6. (a) A student dragging a bar magnet along a test tube partially filled with iron filings. (b) A student's drawing for what she sees the iron filings doing as the magnet is dragged nearby.

After considering these observations with the test tube and computer simulation, some students in the class come up with a whole new way of imagining what is going on inside a nail when it is rubbed. Instead of imagining that there are separate entities of opposite types inside a nail, they now imagine that the entities are now paired. That is, they imagine that opposite types of entities (N and S, or + and -) are paired off in a self-contained magnet-like entity. Each individual entity has its own north pole and south pole. In an unrubbed (unmagnetized) nail, the paired entities are randomly organized, with just as many north pole ends as south pole ends pointed in the same direction. See the 'Before Rubbing' representation in Figure 7, where this student has used a + charge to indicate a north pole end and a–charge to indicate a south pole end in each entity. Thus, the nail as a whole does not have a North Pole or a South Pole. The act of rubbing the nail with a magnet causes all the paired entities to re-orient and align with all the north pole ends pointing in one direction and all their south pole ends pointing in the opposite direction. Thus, the nail as a whole has a North Pole and a South Pole. See the 'After Rubbing' representation in Figure 7.

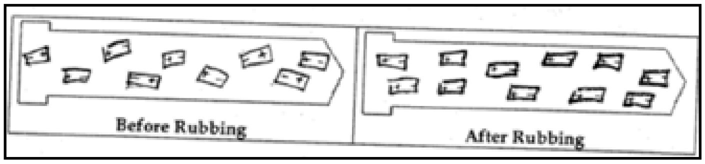

Figure 7. A student model for what she imagines is inside a nail, both before and after the nail is rubbed Here each entity consists of paired charges (+ and-). One end of each entity is considered a north pole, the other end a south pole.

The students in the class who come up with a similar model can then explain to the class why a rubbed nail cut at any place would produce two pieces that were each two-ended. The students assume that the paired entities are intact and could not be broken apart. Thus, when the nail is cut at any place, the cutting always goes in between paired entities. That leaves two pieces, of any size, with the paired entities still aligned. Thus, each cut piece has its own North Pole and South Pole. As soon as some students in the class propose this new model, many others adopt it immediately.

The purpose of the homework that immediately followed the third activity was to provide additional simulator-based evidence to support the new model proposed by some students in class. Students worked with a new computer simulation to explore what happens when a large number of magnets are combined with different orientations. Figure 8 shows some screen shots from the simulation. In (a) the students place four magnets on the screen with their North Poles facing towards the meter and four magnets with their South Poles

Figure 8. A computer simulation that shows the strength of the magnetic field at a position external to a group of magnets. (a) Four magnets with North Poles oriented one way, and four with South Poles oriented the same way. The reading on the field meter has a very low value. (b) Eight magnets with North Poles oriented the same way. The reading on the field meter has a much higher value.

facing towards the meter. The magnetic field meter reads a very low value. In (b) they orient all eight magnets the same way and the field meter reads a much higher value.

(In the class period following this homework the class comes to a consensus on a final model for magnetism. They imagine the entities inside the nail are like ‘baby magnets.’ In an unrubbed nail the baby magnets are randomly oriented and the nail has no North or South Poles. The act of rubbing the nail with a magnet causes the baby magnets to reorient themselves with all their north poles facing in the same direction. That end of the nail will then be a North Pole, and the other end will be a South Pole. Rubbing the nail, then, makes it two-ended. The *baby magnets* model is a simple version of the Domain Model of Magnetism. In the fourth magnetism activity, students apply their *baby magnets* model to explain several new observations with magnets.

The description above illustrates how a carefully designed sequence of experiments can help students construct, test and revise their own models to explain some magnetism phenomena. In this example, computer simulations are used either to reinforce observations made during class, to help focus students attention on critical aspects of their observations, or to provide further support for ideas developed by the students. In other activities and units within the PET curriculum the sequence of activities were carefully designed to enable students to construct and test ideas or models, and computer simulations were used in a supportive or generative manner to complete the hands-on experimental work.

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The work described in this article was supported by the National Science Foundation Grant Number 0096856.

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5. The computer simulation is not exactly analogous to the test tube experiment. The iron filings are not magnets, like the pivoting magnets in the simulation, but the filings become magnetized when the bar magnet is slide across the test tube. Nevertheless, because the behavior of the filings is similar to the behavior of the pivoted magnets in the computer simulation, the simulation helps focus the students’ attention on what happens to each filing.

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Enhancing Student Understanding of 1D and 2D Motions:
The Role of Sequencing Topics, Kinesthetic Experience, Video Analysis and Analytic Mathematical Modeling

Priscilla Laws

For the past 25 years or so the new field of Physics Education Research (PER) has provided university, college and high school teachers with new insights into learning difficulties encountered by introductory physics students. During this time members of the *Activity Based Physics Group* have been developing curricular materials based on the outcomes of PER. Most of the Group's materials employ computer tools that include data collection, display and analysis software along with sensors and video images of real phenomena. These new curricular materials and computer tools are activity-based and flexible. They can be used to create interactive lecture sessions, guided inquiry tutorials in recitation sections, and guided laboratory observations. Elements of the set of curricular materials, known as the *Activity Based Physics Suite*, can be used in many teaching environments from large university lecture and lab courses to small high school classes. Suite materials have been classroom tested and proven to help students overcome many of the learning difficulties identified by PER.

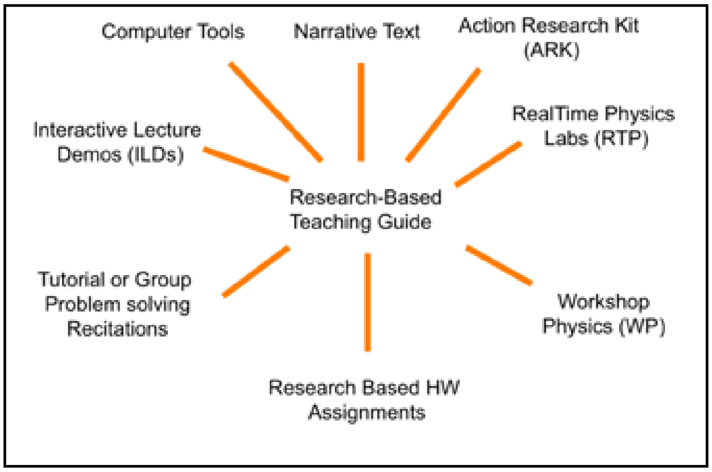

Figure 1: Elements of the *Activity Based Physics Suite* designed for different learning environments.

The *Activity Based Physics Suite* materials were described briefly, and then the rest of the talk focused on *Workshop Physics*, an innovative curriculum first introduced at Dickinson College in 1989. In *Workshop Physics* a carefully designed sequence of collaborative activities replaces formal lectures, recitation sessions and laboratories.

The Workshop Physics Activity Guide, consisting of four guided inquiry modules, was developed between 1987 and 1993 for use in a laboratory setting where about 24 students meet for 2 hours 3 times each week. Students work in collaborative groups to learn physics by predicting, observing and analyzing data from real phenomena. Students often use computer tools for sensor and video based data-collection and analysis.

Figure 2: Workshop Physics students use a motion detector and associated software to track cart motion.

Figure 3: A workshop Physics student feels the centripetal force needed to keep him in a state of uniform circular motion.

Both conceptual learning and the development of facility with the use of analytic mathematical equations to describe physical phenomena are central themes in *Workshop Physics* courses. Thus, the role of pre- and post-testing to measure learning gains in these areas was discussed, along with two commonly used instruments for measuring conceptual and mathematical learning in the mechanics portion of the course: the *Force and Motion Conceptual Evaluation* (FMCE) and the *Mathematical Modeling Conceptual Evaluation* (MMCE). In addition, the speaker presented some examples of kinesthetic activities developed to help students understand Newtonian mechanics. These included: (1) walking in front of a motion detector to create real time graphs; (2) measuring the motion of a bowling ball pushed steadily by a student holding a baton; (3) pulling a student along a level floor with a constant force with and without sliding friction; and (4) measuring centripetal force while a student on a 2D cart undergoes uniform circular motion.

Next an approach to reorganization of the mechanics topics was described. This *New Mechanics* sequence[1] is embodied in several of the *Activity Based Physics Suite* materials including *Workshop Physics, RealTime Physics* and *Interactive Lecture Demonstrations.* This new sequence involves the treatment of both 1D kinematics and 1D dynamics before any 2D motions are considered. This means that projectile motion is not introduced until after students have studied 1D kinematics and Newton's Second Law for linear motion.

After summarizing some of the *Workshop Physics* activities that contribute to conceptual mastery, the speaker showed Pre- and Post-test data for the FMCE Examination presented in E.F. Redish's book on *Teaching Physics with the Physics Suite* cited earlier.[2]

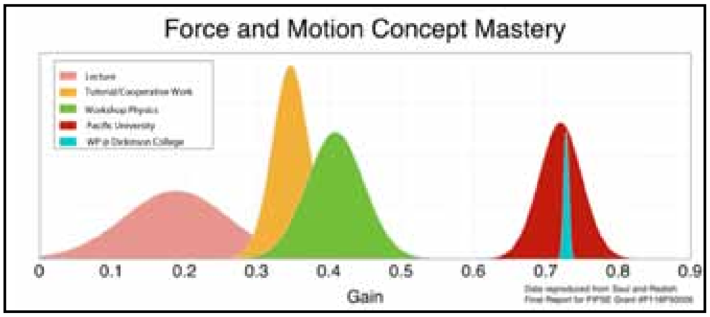

Figure 4: An idealized summary of normalized learning gains on the FMCE in traditional lecture courses (0.19), in courses with weekly hour-long tutorials (0.34), in courses where instructors are in the first couple of years of adoption of Workshop Physics (0.42), and in courses at Dickinson College and Pacific University where the instructors are experienced Workshop Physics adopters (0.71).

Although most of the presentation dealt with conceptual development strategies used in the *Workshop Physics* curriculum, it ended with a summary of a new approach called *Analytic Mathematical Modeling* that has been developed to enable students to relate analytic equations to physical phenomena.[3] Homework assignments were developed that require students to use Logger *Pro* software[4] to obtain data from video segments of real phenomena and determine the equation that models that data.[5]

Unpublished data on Pre-and Post-test gains on the Mathematical Modeling Conceptual Evaluation (MMCE) were compared for *Workshop Physics* students at Dickinson College and those in a traditionally taught calculus-based course at another university where analytic mathematical modeling was not introduced. The Dickinson students did significantly better on their recognition of the physical significance of coefficients for both linear and quadratic functions.

The speaker concluded that "Curricular materials based on the outcomes of physics education research, when coupled with student use of computer based investigative tools, can have a tremendous impact on student learning in introductory physics courses."

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Priscilla Laws is Research Professor of Physics at Dickinson College. Since 1986, she has dedicated herself to the development of activity-based curricular materials and computer software to enhance student learning in introductory physics courses. This work has included several publications that are part of the Activity-Based Physics Suite. She has received a number of awards for educational innovations and software development. The most notable include the Charles A. Dana award for Pioneering Achievement in Education (1994), the Robert A. Millikan Medal from the American Association of Physics Teachers (1996), and the International Commission on Physics Education (ICPE) Medal in recognition of distinguished contributions to Physics Education (2008).

Combining hands-on and virtual experiments with visualizations to teach contemporary topics to non-science students

Dean Zollman

For several years we have had a general goal of making the physics of the 20th and 21st centuries accessible to students with limited mathematical skills and little science background. We try to focus the students' attention on why we understand things about nature and how we come to understand that rather than just what the phenomenon is. Our method is based on the well-known results of physics education research. The students need to be actively involved in their learning. Further, they should learn about conceptual models. Our approach in recent years has been to use a combination of hands-on activities, written documentation, computer visualizations, videos and analogies which we put together in an active learning package.

As an example I will describe the components of an active learning package on the study of an electron diffraction experiment. This lesson includes a program that we created ourselves and the work of several groups, including a research level experiment and a commercial film animator. All of the components are available on the Web. With the links in this article you can try it yourself.

We use electron interference as the first introduction to the wave behavior of matter. This approach is consistent with research that indicates students gain from a concrete experience before the introduction of the theory. It is also similar to the approach taken by Feynman. In this case the concrete experience is the electron diffraction experiment and the comparison of its results with those of a two-slit experiment with light. Thus, we usually begin with a look at two-slit interference patterns with light. The students look at the interference of a red light and then a green light. The critical feature is observation of the change in the interference pattern when one changes from red to green light. We do not ask the students to make measurements or calculations–just notice how the pattern changes as the wavelength changes.

Now, we look at electrons. Many universities have an electron diffraction tube in which case the students can conduct the experiment. However, many students do not have access to them so fortunately we have two different computer-based arrangements that enable the students to conduct an experiment.

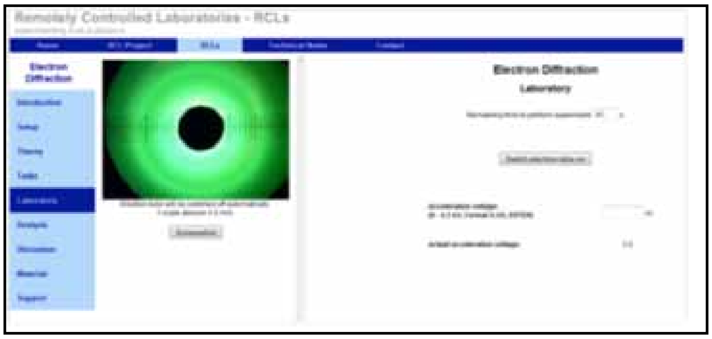

Figure 1: A screen from the Kaiserslautern remote control electron diffraction experiment.

The physics education group at the University of Kaiserslautern has a set of experiments which can be controlled remotely. The instructions are available in both English and German, so our students can complete the experiment. Students can select the electron diffraction experiment, enter a voltage and see the interference pattern on a real electron diffraction tube. Figure 1 is a screen capture of the remote experiment. To view the electron diffraction experiment go to http://rcl.physik.uni-kl.de/, select English, then RCL from the top menu. Electron diffraction will be the first choice on the left.

For our students we have limited access to the electron diffraction apparatus. We have only two, and they are shared by several classes. Therefore, as an additional experience our students do the remote control lab and the instructors tell each student, "Do four voltages and ship them to me by email and we'll put them all together in one class." Thus, we have a relatively large data set to look at in class.

Interactive screen experiments provide students with a way to complete virtual experiments that seem almost real. These types of experiments were developed in Germany under the name "Interaktiv Bildschirm Experimente" or IBE. A screen capture of an IBE for electron diffraction is shown in Figure 2. These experiments involve a large number of individual still pictures. The pictures include essentially every configuration and variable setting that the developer could think of. Students can turn on the apparatus and conduct the experiment by turning the dials. They can then record the variables and the resulting interference pattern. The IBE can sometimes be frustratingly realistic. For example, I have set it up, turned the voltage dial and nothing happens because I forgot to turn on the heater switch. (Some IBEs require students to connect the wires; this one does not.)

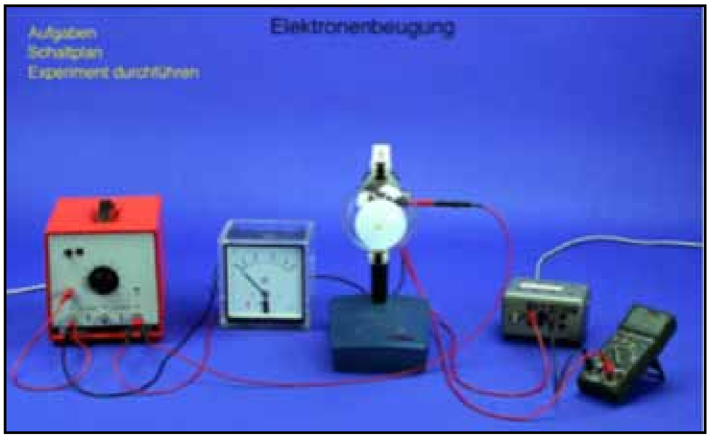

Figure 2: An interactive screen experiment for electron diffraction.

http://www.uni-due.de/physik/fbphysik/probestudium/WS0708/elektronenbeugung/elektronenbeugungwp.html

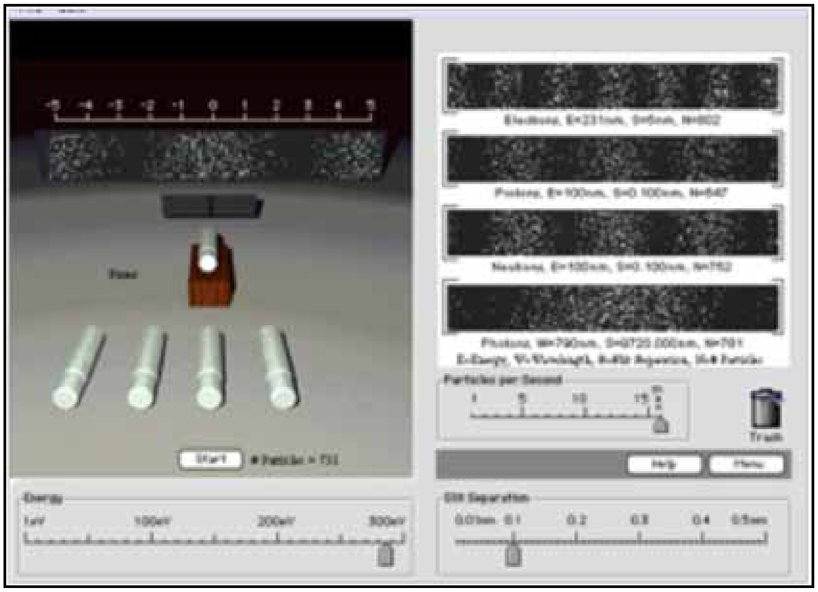

Figure 3: A screen shot from the *Visual Quantum Mechanics* double slit visualization. Each of the white cylinders represent a "gun" for different types of particles, electrons, protons, neutrons, photons and pions.

Once students see that an interference experiment with an electron is something interesting, we introduce some of the principles related to the phenomenon. Our approach includes having students conduct several virtual two-slit experiments with electrons and other forms of matter. Using the *Visual Quantum Mechanics* interactive simulation (Figure 3) we establish the relationship between the wavelength and energy of the particle. More details are presented in reference 1. You can run the two-slit experiment at http://web.phys.ksu.edu/vqm/software/online/vqm/html/doubleslit/index.html

As a summary we have the students watch an animated sequence from *What the Bleep Do We Know*, a commercial film with which most of our students are familiar. See http://www.whatthebleep.com. (This animated scene is not from the theatrical release of the movie. However, it is included in the extended director's cut which is five hours long. It is also posted on the movie's web site and YouTube, so you can avoid watching the 5-hour version.) I have my students look for errors in this scene. For example, the single slit diffraction is not treated correctly in the film. By the time we are done, most of them are able to find it.

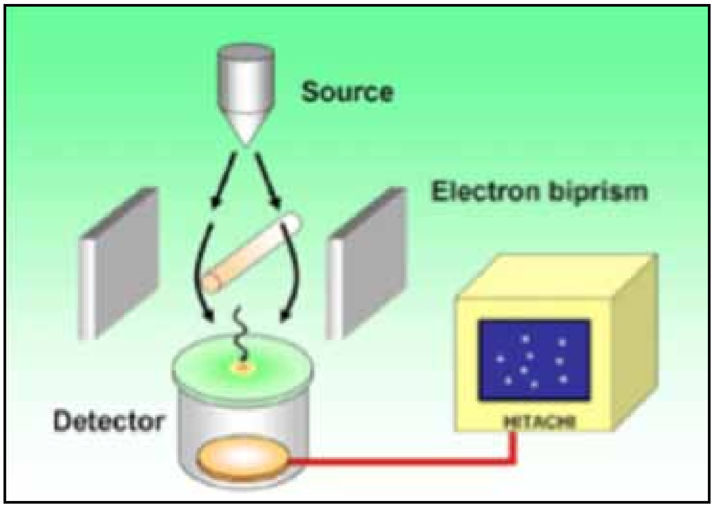

Figure 4. A diagram equivalent to a double slit experiment for electrons. http://www.hitachi.com/rd/research/em/doubleslit.html

(In the film, "Dr. Quantum" mentions items that we have not yet discussed such as wave functions. I ask students to keep a list of these ideas, so that we can discuss them later.)

Another question that we address is what happens if the electrons move through the double slit apparatus one at a time. Our interactive visualization enables students to control the rate of particles. Of course, simulations can do anything, so we need to show some connection with reality. Fortunately, Tonomura, who is a research physicist for Hitachi in Japan, has done the experiment[4] and put the results on the Web. A schematic diagram of his two-slit experiment for electrons is shown in Figure 4. A video of the individual electrons striking the screen and gradually building up an interference pattern is available at http://www.hitachi.com/rd/research/em/doubleslit.html and on YouTube. Once students accept that this effect is real, we start discussing difficult issues such as, "Does each electron go through one slit and then interfere (whatever that means) with another electron rather than interfere with itself?"

Returning to the visualization we repeat the experiment with electron moving through the apparatus one at a time and compare it to a similar photon experiment. However, as shown in Figure 3, several other particles are available. Each of them is based on results of research we completed while developing *Visual Quantum Mechanics*. In early versions we added only a nucleon so that students could investigate how the interference pattern varied with mass. However, we discovered that a common conception of students was that these particles were spreading out all of the electrons or nucleons have the same charge. Therefore, they were repelling each other. We now have protons and neutrons so that they can compare the charge dependence for particles of almost identical mass. Of course they see no such dependence.

In this example, I have shown how an instructor can start this study of the wave behavior of matter with hands-on activities, even if you do not have the apparatus. Then introduce new concepts and have the students do further applications. This is a basic learning cycle trying to build models as we go and in all of that we use a combination of different types of learning materials. These materials provide both hands-on experiences similar to doing a real experiment and visualizations that help students construct models of the physical phenomenon. Thus, by collecting all of these materials in a lesson that is consistent with physics education research, we can provide a learning experience on a rather abstract topic.

The KSU portion of the work described here has been supported by the National Science Foundation.

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Looking at real experiments first: Curricular and technical approaches for teaching elementary quantum physics

Jan-Peter Meyn

1 Motivation

Declining interest in physics among adolescents is a universal phenomenon. One approach to making physics instruction more interesting is to cover current research topics on an elementary level. Many exciting topics are covered in science magazines. Quantum optics research is very suitable as an introductory example: Research is conducted in small groups, the experiments are tabletop-size and the mathematics are relatively simple. Originally, quantum optics have been taught in graduate courses, but a number of undergraduate courses including laboratories have been established over the last decade [1–3].

Our goal is to extend quantum optics teaching to students in secondary schools. The teacher then would not only talk about modern science, but also use recent terms and tools. In particular, *photons* are not treated as obscure particles of light, and quantum state preparation is discussed in detail: Single photons are prepared by parametric down conversion of photon pairs and measuring temporal coincidence of detection in spatially separated detectors. Real or interactive experiments are inseparable parts of the instruction.

2 Curriculum

We postulate that talking about quantum physics should involve quantum phenomena, which are not observable in classical physics. This is very well established in mechanics, for example, a free falling body is always treated as a rigid body unless it is so small and slow that one has to treat the problem with a matter wave package. On the other hand, the term *photon* is often used to explain the simplest phenomena of light and vision even in lower grades of secondary schools. We believe that this habit is a source of various misconceptions.

2.1 Hierarchy of theories

Traditionally, the quantum theory of light is regarded as part of quantum electrodynamics, which are taught as an extension of quantum mechanics, which again are an upgrade to classical mechanics for very small and slow particles. Ideas and terms of both classical and quantum mechanics come from tactile perception. The great miracle of quantum mechanics is the fact that quantum objects do not behave like we think, i.e. a particle such as the electron goes two ways in the double slit experiment, to name but one obscure characteristic.

For quantum optics as a special branch of quantum physics, another approach is obvious: Instead of going through all mechanics and electrodynamics, quantum optics are simply regarded as optics for non-classical states of light. Optics itself come from visual perception. A sketch of the hierarchy of theories is shown in figure 1.

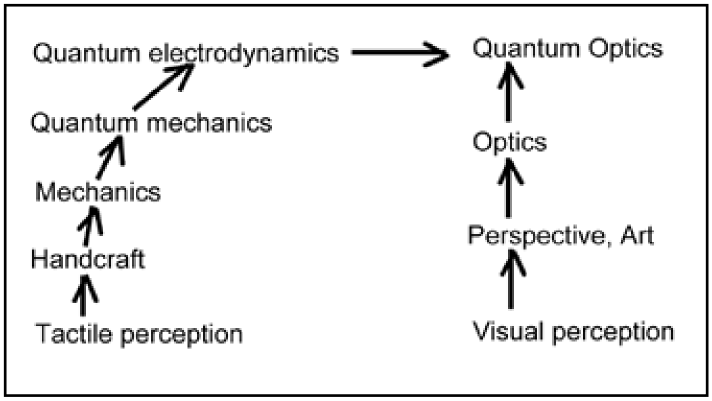

Figure 1: Hierarchy of theories and teaching order. Usually, photon physics is reached after extensive education in quantum mechanics. Alternatively, quantum optics is a branch of optics, involving no mechanics at all.

Despite practical issues, it is well worthwhile to have a closer look at the alternative road: Nonclassical light behaves like light in any case, and particular quantum states such as single photon states just add certain quantum phenomena to the set of possible observations. There is no classical to quantum boundary as in quantum mechanics, where the term particle becomes useless and has to be replaced by the completely different concept of the wave packet. When looking at matter, one realizes that matter starts to behave like light at low momentum. This is quite astonishing, but rather a matter issue than a quantum issue. It is well possible to talk about advanced quantum physics including, for example, entanglement, without discussing this peculiar behaviour of matter at the very beginning of a curriculum.

To put it in plain and simple terms: Optics is the natural approach to quantum physics. Matter optics is a suitable description of quantum phenomena, but light mechanics is not.

2.2 Classical to quantum transition

Optical phenomena are spatial phenomena. There is no easy way to observe the oscillation of the electromagnetic field directly. In our approach, the classical to quantum transition is characterized by the introduction of temporal relationship as a necessary (but not sufficient) condition.

In a standard single photon experiment, temporal relationship is introduced by a coincidence circuit for preparing single photon states. Alternatively, single photons can be generated on demand, where *on demand* again means a temporal relationship. In any quantum measurement, a quantum state interacts with a macroscopic apparatus instantly and irreversibly.

3 Praxis report

3.1 High school quantum physics

Based on the concept of introducing students to quantum physics via optical terms and experiments, a course for a grade 12 physics class has been developed and tested. Classical optics is inspired by reference [4].

A hallmark of optics is non-locality, as opposed to particle location in mechanics: i) Visual orientation relies on viewing distant objects from a fixed direction. ii) All optical paths through a lens contribute equally to an image. Blocking part of the lens will dim the image homogenously. iii) Constricting optical paths by a stop causes diffraction. There is no way of preparing a single light beam. iv) Entangled photons exhibit non-local correlation. The non-local aspects are pointed out with experiments.

3.2 Physics Experience Programme

Quantum optical experiments are based on apparatus which are not commonly found in high schools. Therefore we offer a physics experience programme where high school students can work at four stations with lasers, optical fibres, polarisation rotators and research laboratory mechanics. The students get to know all optical equipment, except those necessary for single photon quantum state preparation, namely the parametric down conversion crystal and the coincidence circuit. When looking at a quantum optics experiment afterwards, the students are less overwhelmed by the many compounds, as they know almost every component on the table by own experience.

3.3 Interactive Screen Experiments

Local schools can visit our quantum optics laboratory, but the number of locations with such a facility is quite limited so far. Therefore we provide interactive screen experiments via the internet [5].

3.4 The size of quantum objects

It turned out, that among the different experiments possible with single photon states, entanglement of a photon pair is the most interesting to students. In our experiment, we point out the non-local correlation of entangled pairs, when each component photon seems to be transmitted or reflected by a beam splitter randomly [6]. Obviously, the entangled photon pair has a size of the order of the optical table, i.e. this quantum object is not tiny at all. The experiment contradicts classical expectations, because it is a true quantum experiment, but still it fits into the framework of non-locality in optics.

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AAPT/PTRA PROFESSIONAL DEVELOPMENT PROGRAM

A Model for Successful Teacher Professional Development

James H. Nelson and George A. Amann

With the help of National Science Foundation (NSF) and the American Physical Society (APS) funding, the American Association of Physics Teachers (AAPT) has developed the Physics Teaching Resource Agent (PTRA) model for successful physical science and physics teacher professional development. This model includes development of peer mentors and professional development leaders, systemic infrastructure, assessment instruments, and a curriculum based on experienced mentors and physics education research.

The AAPT/PTRA curriculum is supported by a series of AAPT/PTRA Teacher Resource Guides. These guides serve not only as a resource for the teacher's professional development, but also are appropriate for teachers' continued use in their grades 7 to 12 classrooms.

Need For "Highly Qualified" Teachers

In the United States as a whole, as well as in individual states there is a looming shortfall of highly qualified teachers of physics and physical science. This shortfall is a result of pressure at both ends of the teacher supply and demand continuum.

On the demand side, more and more students are studying physics topics in Environmental Science, Integrated Science, Physical Science, Physics, Principals of Technology, Robotics, et cetera. This is being driven by an increased realization on the part of educators that physics is the fundamental science upon which an understanding of all other sciences and engineering is built. As our national medical, economic and defense systems become increasingly dependent upon an understanding of science and the products of science, more and more students are preparing themselves for the future by studying fundamental sciences, which includes physics topics. This change is sometimes characterized by the phrase "Physics for All." Another factor is the growing movement to teach physics first in the typical high school science curriculum sequence. All this is occurring as states are setting higher expectations for teachers and student achievement.

On the supply side, the "baby boomer" generation of physics teachers are beginning to retire leading to an increased need to find highly qualified teachers as required by the federal "No Child Left Behind Legislation.[1]" With very few students graduating from college with the goal of becoming a professional science teacher, the shortfall is growing. The most likely source of meeting present and future teacher needs is by alternative certification and by recertification of existing teachers. Both of these groups need the opportunity to prepare them to fill their expected role. The AAPT/PTRA Professional Development Program has developed a professional growth model that will help these individuals grow into outstanding teachers.

Out-of-Field Teaching in Middle and High School Grades

According to U.S. Department of Education, National Center for Education Statistics, "The Condition of Education 2003", NCES 2003-067, Washington, DC, researchers have explored the hypothesis that teachers' knowledge and ability are associated with student learning in the classroom. These studies have found that students learn more from mathematics teachers who majored in mathematics than from teachers who did not (Goldhaber and Brewer 1997) and more from mathematics and science teachers who studied teaching methods in the subject they teach than from those who did not (Monk 1994; Goldhaber and Brewer 1997). These findings have prompted further examinations of "out-of-field" teachers (i.e., teachers who lack a major and certification in the subject they teach.)

Students in the middle and high school grades were more likely to have out-of-field teachers in mathematics, foreign language, social science, and physical science classes than in their art, music, and physical education classes.

Overall, out-of-field teachers were more common in physical science than in any other regular subject in both the middle and high school grades. They taught 42 percent of physical science students in the middle grades and 18 percent in high school.

The issue was summarized in the report *Out-of-Field Teaching and the Limits of Teacher Policy*, A Research Report co-sponsored by Center for the Study of Teaching and Policy and The Consortium for Policy Research in Education, Center for the Study of Teaching and Policy, September 2003

The failure to ensure that the nation's classrooms are all staffed with qualified teachers is one of the most important problems in contemporary American education. Over the past decade, many panels, commissions, and studies have focused attention on this problem and, in turn, numerous reforms have been initiated to upgrade the quality and quantity of the teaching force. This report focuses on the problem of under-qualified teachers in the core academic fields at the 7-12th grade level. Using data from the nationally representative Schools and Staffing Survey, conducted by the National Center for Education Statistics, this analysis examined how many classes are not staffed by minimally qualified teachers, and to what extent these levels have changed in recent years. The data show that while almost all teachers hold at least basic qualifications, there are high levels of out-of-field teaching - teachers assigned to teach subjects that do not match their training or education. Moreover, the data show that out-of-field teaching has gotten slightly worse in recent years, despite a plethora of reforms targeted to improving teacher quality.

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[1] http://www.ed.gov/nclb/landing.jhtml

Richard M. Ingersoll, University of Pennsylvania

Components of AAPT/PTRA Professional Development Program
According to a 2003 study completed by Horizon, Research, Inc. http://www.horizon research.com/, on K-12 Mathematics and Science Education in the United States, high quality teacher professional development must include:

1. Focus on content knowledge,
2. Emphasis active learning
3. Promote content coherence
4. Provide a large amount of training sustained over time, and
5. Encourages collaboration among teachers.

As a result of experience and research, the AAPT/PTRA leadership has developed a model for successful teacher professional development. The features included in the AAPT/PTRA Professional Development Model include:

- A consistent and known curriculum for Professional Development consisting of the sequence of Kinematics, Newton's Laws, Energy, Momentum, Electricity (DC Circuits and Electrostatics), Waves, Optics, and Sound. It has been documented that a consistent and logical sequence of professional development events over a period of time, has a much better rate of success than a random collection of events. See for example, Hill and Ball (2005). http://www-personal.umich.edu/~dball/BallWeb/SelecteJournalArticles.html

- Highly qualified teachers can benefit from a smorgasbord approach to professional development, because they have the personal internal infrastructure into which they can plug the random events they experience; however, the new or developing teacher does not have this infrastructure and cannot incorporate the random events they experience into a consistent infrastructure. Professional development must be more than a collection of activities. Participants must understand how the activities performed during a professional development experience build on one another to tell a story of the science being learned. During an AAPT/PTRA professional development, the learning experience is a gentle slope rather than cliff! During AAPT/PTRA Institutes and Follow-up Workshops the following questions are the focus of the participant's experience.
    a. How does an activity help students develop a concept?
    b. How does the lesson/activity help students overcome misconceptions?
    c. How does today's lesson/activity relate to the previous lesson?
    d. How does today's lesson/activity prepare for the next lesson?

In order to effectively impact classroom practice, participants/teachers need to experience the lesson as if they were students and understand the purpose of the activity in the curricular sequence. As participants/teachers articulate the purpose of the Professional Development, they will begin to internalize its relevance. Changes in beliefs often come after teachers use a new practice and see the benefits (Ball & Cohen, 1999).

- Teacher content knowledge in mathematics and science is closely linked to student performance (Darling-Hammond, 2000); science teachers who improved content knowledge and deepened pedagogical reasoning had greater improvement in student's achievement (Heller, Kaskowitz, Daehler, & Shinohara, 2001). Since AAPT is the world's foremost professional society for physics education, AAPT provides the credibility for the AAPT/PTRA Program, the AAPT/PTRA curriculum, and AAPT/PTRA teacher professional development. Each AAPT/PTRA curriculum Teacher Resource Guide has been developed by experienced and knowledgeable high school physics teacher(s). This assures that the activities and instructional techniques in the Teacher Resource Guide are effective both during the professional learning experience and when teachers use the activities in their classrooms. Each AAPT/PTRA Teacher Resource undergoes rigorous review by the Publication Committee of the AAPT. The review process assures that the content and pedagogy of the AAPT/PTRA Teacher Resource Guides are world class. Consistent curriculum at all sites is based on AAPT/PTRA Teacher Resources Guides and leadership training in order to facilitate system wide AAPT/PTRA evaluation.

- AAPT/PTRA mentors and leaders undergo yearly training in research based pedagogy, including guided inquiry, instructional use of technology, in addition to AAPT/PTRA curriculum and content so they are better prepared as role models for new and crossover science teachers. This approach takes advantage of the old adage, "… teachers teach the way they were taught."
- The AAPT/PTRA leadership selects Regional Sites (RS), usually on a college campus, to host AAPT/PTRA Summer Institutes and follow-up sessions. A college or university professor is selected to be the Regional Coordinator (RC) for this site. Although the AAPT/PTRA professional development model does not use the college or university professor(s) as teachers within the program, the college or university professor is an important component of the collaborative support structure for the program. Each chosen institution serves as a Regional Site providing the support infrastructure for the program. This support includes the use of classrooms, laboratories, technology, and laboratory equipment, as well as a source of housing and meals during the AAPT/PTRA Program summer institutes and follow-up sessions.

- The AAPT/PTRA Program is committed to provide over 100 hours of consistent professional development for participants. Several strategies have been developed to provide incentives for participants to continue for the full 100+ hours. One incentive includes increasing the participant's stipend as they complete more hours of training. In addition, the ability of the participants to purchase equipment at reduced rate from cooperating vendors is only available after completing a topic.
- Consistent curriculum at all sites is based on the AAPT/PTRA

Teacher Resource Guides in order to facilitate system wide AAPT/PTRA evaluation.

- The AAPT/PTRA Program has developed formative and summative content assessment instruments for use with second-tier participants. These assessment instruments are used to gather data for formal assessment of the program. For examples of Participant Content Assessment Instruments and Sample Assessment Results see AAPT/PTRA Website.

- Since the key measure of effectiveness of teaching is the growth and development of student skills and knowledge, the AAPT/PTRA Program has developed diagnostic and summative content and skills assessment instruments for use with students taught by second-tier participants. For examples of Student Content Assessment Instruments and Sample Results see AAPT/PTRA Website.

- Formative assessments are used during the AAPT/PTRA professional development summer institutes to determine the participants' progress. There are assessments of their conceptually resistant ideas, assessment of areas that need to be re-addressed, etc. For examples of Formative Assessment Instruments and Sample Results see AAPT/PTRA Website.

- Full commitment for three summers and two follow-up sessions per year is expected of participants who attend AAPT/PTRA Summer Institutes.

- In kind support for the program is provided by cooperating vendors (e.g., PASCO, Prentice Hall, Texas Instruments, Vernier, etc.) Vendors provide up to date equipment for use during professional development institutes, and reduced purchase prices for participants who have completed a PTRA topic.

- Instructional technology is incorporated into AAPT/PTRA summer institutes and follow-up sessions. Although the technology is used to compliment the science learning of the students, alternative instructional methods are also provided for teachers who do not have the technology available. The AAPT/PTRA Program recognizes however that participants should experience the instructional advantages of using appropriate technology in order to be prepared for future technological activities in their school. These activities can make major improvements in student learning.

- AAPT/PTRA summer institutes and follow-up sessions spend time on implementation strategies, overcoming barriers to implementation, and general guidelines to successful instruction based on the needs of participants' students and availability of materials at their school.

- To develop a continuing learning community among participants, the AAPT provides ListServs and websites for continual peer collaboration and communication.
- One experienced AAPT/PTRA is assigned as the Lead PTRA to function as a liaison between the AAPT/PTRA Program, the RC, and the participants at each Regional Site. This partnership brings together the classroom experience and training of the Lead PTRA who will conduct the activities within the academic setting provided by the local institution.

- Peer reviewed criterion-referenced assessments that can be administered to teachers and students are used. These assessments are particularly valuable in determining student success as a result of the AAPT/PTRA Professional Development for their teachers. For examples of Criterion-Referenced Assessment for students and teachers and Sample Results see AAPT/PTRA Website.

- The AAPT/PTRA Program provides continuation education credits via AAPT as well as inexpensive graduate credit through the University of Dallas. This provides an additional incentive to the participants.

- The AAPT/PTRA Program tracks the number of hours each participant has experienced as a member of the program on each of the program topics. Thus the program provides them with proof of meeting their professional development obligations for their districts.

- A website with information about the AAPT/PTRA Program is available. See http://www.aapt.org/PTRA/index.cfm

- The AAPT/PTRA Program provides weeklong summer institutes with 12 hours of follow-up sessions during the school year. The follow-up sessions are based on the previous summer institute topic(s) and provide a support system for the teachers during implementation of the new content, activities and instructional strategies. The five-day format of the summer institute is preferable to a once-a-month or random format during the school year. During extended periods of time such as this, participants can concentrate on the topic being studied. Each AAPT/PTRA topic has a theme as well as a scope and sequence. The institute activities constitute a consistent story with a logical development of concepts. (See kinematics curriculum example below.) A value added aspect of the weeklong summer institute is the camaraderie that develops among the participants. When a group of teachers are brought together, it takes time and effort to have them coalesce into a group of capable of carrying out collaborative learning experiences that would be expected of their own students Until the participants spend some informal as well as formal time together they are less likely to be open about dealing with the problems associated with their teaching and their own student's learning.

- Equations of the relationship among variables that represent physical phenomena (i.e., $\Delta PE=mg\,\Delta h$, $d=v(0)+vt$, $F=ma$, et cetera) are initially developed from laboratory activities rather than from a textbook or teacher lecture. During the laboratory activities data is taken by participants and then logically analyzed to determine the relationships among the variables that they have monitored. Activities are used to introduce concepts rather than verify concepts. This is typically called the constructivism approach. (ABC–Activity Before Concept)

- Research based appropriate models of instruction are used (e.g., Learning Cycles, Modeling, guided inquiry, self-directed learning, ranking tasks, et cetera) as the foundation for instruction.

AAPT/PTRA - Goals & Activities

The AAPT/PTRA Program goals include providing an opportunity for upper elementary, middle, and high school teachers to experience professional growth in the areas of physics and physical science content (e.g., Kinematics, Energy, Newton's Laws, etc.), use of technology (e.g., electronic measurements, graphic calculators, simulations, etc.), and teaching techniques based on physics education research.

Teachers identified as outstanding in the four areas listed below have been designated, trained and certified by AAPT as AAPT/PTRAs. These teachers were the first to experience this professional growth. These first tier AAPT/PTRAs attend annual AAPT/PTRA professional development sessions on workshop leadership, organization, and delivery of content topics. These teachers continue to be provided with experiences during the annual AAPT/PTRA National Summer Institutes to grow as workshop leaders. The four areas used to critique applicants for AAPT/PTRA status are:

1. Evidence of Content Knowledge
2. Evidence of Creativity in Teaching
3. Evidence of Interest in Personal Professional Growth
4. Evidence of Leadership Potential

A Boston College study, *TIMSS (Third International Mathematics and Science Study)* Physics Achievement Comparison Study, published in April 2000 shows that students of teachers who have attended NSF funded projects, such as AAPT/PTRA Professional Development Program, performed significantly better on the TIMSS physics assessment. See www.timss.org. The USA overall mean is 423 while the mean for students of teachers who have attended NSF sponsored professional development is 475. In addition Horizon Research, Inc has documented the success of the AAPT/PTRA Program. This research indicates that teachers who attend AAPT/PTRA workshops are more confident in their own physics content knowledge and thus are more likely to make a commitment not only to use of technology, but also to use the results of successful and research-based teaching strategies (e.g., modeling, directed guided inquiry, self-directed learning, ranking tasks, etc.)

The AAPT/PTRA Program has established an infrastructure that leads to interaction and sharing by teachers. This is described in the AAPT/PTRA Handbook for Workshop Leaders (2006-2007 Edition), and an article in the AAPT *The Physics Teache*r "Physics Teaching Resource Agent Program" TPT, April 2001.

The AAPT/PTRA workshops are of two types: content specific and teaching strategies specific. Content specific subjects include (e.g., Kinematics, Energy, Geometric Optics, Momentum, Newton's Laws, and the Electromagnetic Spectrum. etc.). Workshops dealing with teaching strategies include (e.g., Role of the Laboratory, Use of TI-83/84 in Teaching Physics, Role of Demonstrations, Guided Inquiry. etc.)

TEACHING ABOUT KINEMATICS/MOTION is a typical content centered workshop. The outline of this workshop covers the basic topics for the study of motion and requires a minimum of 18 hours to complete. Using a constructivist approach, participants develop definitions for position, distance traveled, displacement, time interval, instant in time, frequency, wavelength, speed, velocity and acceleration based on their own observations. In order to develop these definitions, have measured fundamental quantities such as position; distances traveled, displacement, wavelength, frequency, and time intervals, as well as calculated instantaneous speed, average speed, linear acceleration, and acceleration in circular motion. This workshop enables the teachers to experience novel approaches and activities to the teaching of kinematics. As described, all concepts and equations are developed as participants do the laboratory activities.

Participants may do the activities with toy cars and airplanes.

The activities are designed to help students distinguish among:

- Time as an Instant, and Time as an Interval.
- Position, Distance Traveled, and Displacement.
- Instantaneous Speed and Average Speed for Uniform Linear Motion
- Instantaneous Speed and Average Speed for Uniform Circular Motion
- Speed and Velocity for Circular Motion
- Acceleration, Speed and Velocity
- Linear Acceleration and Circular Acceleration
- Verbal, Mathematical and Graphical Representation of Motion
- Sign of Vector Quantities (e.g., Displacement, Velocity, and Acceleration)

Successful laboratory activities rely on the instructional use of the following fundamental measuring instruments: ruler, magnetic compass, computer motion probe, protractor, photogate, stopwatch, and vibration timer.

The approach is unique; the content rigorous, and the classroom strategies are consistent with Physics Education Research and the National Standards. AAPT/PTRA workshops are appropriate for upper middle school (i.e., Grade 7-8) through high school teachers.

Outline of a Typical AAPT/PTRA Weeklong Institute Kinematics/Motion

Compare/Contrast/Measurement: Time as an Instant, Frequency,

Time as an Interval, and Period Using Pendulum and/or Flashing Light.
- Measurement of Time Intervals
- One Second Timer Challenge
- Pendulums on Parade
- Period of a Pendulum using a Photogate
- Frequency versus Period using a Flashing Light

Compare/Contrast/Measurement: Position, Distance Traveled, and Displacement
- Traveling Washer in One Dimension
- Traveling Washer in Two Dimensions
- Where am I?

Compare/Contrast/Measurement: Speed and Velocity
- Toy Car moving with Uniform Linear Motion
- Toy Car moving with Uniform Circular Motion
- Movement of Waves (Wave Equation compared to Speed Equation)
- Instantaneous Speed, Average Speed, Initial Speed and Final Speed Using a Toy Car Coasting Down an Inclined Plane using a Photogate Timer.
- Analysis of Motion Using Graphs Made from a Ticker Tape Timer.

Compare/Contrast/Measurement: Acceleration Using Toy Cars and Toy Airplanes
- Speeding Up
- Speeding (Slowing) Down
- Changing Directions
- Measuring acceleration with a Liquid Level Accelerometer.
- Linear Acceleration and Circular Motion Acceleration

Calculations using basic kinematics definitions, graphs, and equations
- Position versus Time Graphs (Motion Probe)
- Velocity versus Time Graphs (Motion Probe)
- Acceleration versus Time Graphs
- Basic Linear Kinematics Equations
- Freely Falling Objects (Free Fall Timing)
- Basic Uniform Circular Kinematics Equations

All of these topics are develop with inquiry based laboratory activities.

Wingspread Meeting

In 2005 the Education Commission of the States with support of the NSF invited a group of exerts to a Wingspread Conference who identified a variety of areas that policymakers and education leaders should address to improve mathematics and science education. According to the Education Commission of the States report, *Keeping America Competitive: Five Strategies To Improve Mathematics and Science Education* by Charles Coble and Michael Allen, July 2005,[2] the over-reliance on the mathematics and science talent of foreign students represents a major potential weakness in the future competitiveness and vitality of the U.S. economy and workforce. To help address this weakness, policymakers and education leaders must ensure the U.S. education system is successfully preparing its students for careers in science and mathematics.

Five Strategies

The experts, which ECS and NSF gathered at this Wingspread meeting, identified a variety of areas that policymakers and education leaders should address to improve mathematics and science education. Of particular importance are the following essential needs:
1. To effectively assess student learning in mathematics and science
2. To strengthen teacher knowledge and skills in science and mathematics
3. To ensure high-quality mathematics and science teachers are available to all students including the most disadvantaged students
4. To ensure strong leadership from the higher education community, especially from university presidents
5. To promote public awareness of the importance of mathematics and science education to the country's future.

As explained above, the AAPT/PTRA Program is uniquely positioned and prepared to address numbers 1, 2, 3 and 5 on this list. With continued funding, the program hopes to fulfill its stated goal of improving physics education for all students in the United States.

If the physical science teacher shortfall problem is not solved, our nation runs the risk of increasing the percentage of the population that is scientifically and technologically illiterate. A scientifically literate population is critical for the nation's economic, medical health, military security, and the general feeling of citizens that they are a part of the nation's present and future.

The Authors:

J*im Nelson has many years of experience at several levels of education, being the principal investigator of several grants funding the activities of the PTRA. He has received numerous teaching and professional service awards. He served as president of AAPT in 2004. He is author of numerous publications in physics education journals.*

George Amann has been involved in teaching in the New York State school system for many years and has received numerous teaching awards He has been in the leadership of the New York State Section of AAPT and in the PTRA, where he has directed more than 50 teacher workshops.

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[2] Charles R Coble; Michael Allen; Education Commission of the States.; National Science Foundation (U.S.); Johnson Foundation (Racine, Wis.)

Topical conference on laboratory instruction BEYOND THE FIRST YEAR of College

Gabriel Spalding

The support of the FEd (along with that of ALPhA, the NSF, APS, AAPT, PIRA, ComPADRE, the Physics Departments of the University of Pennsylvania and Drexel University and the participating vendors) will be very important to the success of this conference. That is, your support is needed!

The Conference on Laboratory Instruction Beyond the First Year (BFY) will be held at the University of Pennsylvania and Drexel University, Wednesday, July 25 - Friday, July 27, 2012. This will be an extremely unusual opportunity for *hands-on* exposure to an extremely broad smörgåsbord of contemporary instructional labs appropriate to Modern Physics Labs, Electronics, Optics, Advanced Labs, as well as key instructional labs in Statistical Physics, Condensed Matter and Materials Physics, Quantum Mechanics, *etc*. At the same time, the conference will serve as an opportunity to discuss a range of curricular models that allow for enhancement of the undergraduate physics major.

A survey regarding the status of laboratory instruction beyond the first-year courses has been conducted by ALPhA (the Advanced Laboratory Physics Association); preliminary results indicate that, even at a number of the larger institutions, physics majors often require **only two semesters** of laboratory instruction beyond the first year, which places an extraordinary *burden* upon those required courses. Curricular revision is possible, with some institutions adding just a few key labs sprinkled throughout the core courses of the major, while other institutions seek to "co-value" experiment with the formal, non-laboratory part of the physics course sequence. The time is ripe for cross-institutional dialog on such "big picture" issues.

Arguably, one of the reasons why physics is a "good" undergraduate major is that its traditional, formal coursework is a "spiral curriculum," that is, one that revisits, reinforces, and refines key concepts. On the other hand the *cohesion* of laboratory curricula over the four-year experience of a typical major requires much more intentional planning. Some programs have given these issues serious consideration. More are taking up the issue. Again, the time is ripe for cross-institutional dialog.

Often, though, it is when we focus the conversation at the level of discussing *particular courses* or even *particular experiments* that we have some of our most productive exchanges about modernizing our curricular content and our pedagogy. So, this "BFY" conference will have breakout sessions and a great many hands-on workshops allowing this sort of focused interaction.

Among the sub-topics covered, we will highlight those aimed at demonstrating quantum mechanics in the undergraduate curriculum (*e.g*., demonstrating the existence of photons, quantum correlations and ***single-photon*** interference, indistinguishability and the quantum eraser, entanglement and statistical tests of Bell's inequalities). This summer ALPhA managed the advertising and registration for a faculty development workshop focused on these particular instructional labs (at Dickinson College, June 17-18, 2010). It is notable that this sold out quickly, demonstrating a high level of interest among instructors. While instructor and student interest in such topics can be quite high, these can nevertheless pose pedagogical challenges. Yet a number of groups have begun work to re-vamp the four-year undergraduate curriculum so that students will have already had hands-on experience with the relevant equipment, techniques, and key conceptual aspects by the time they encounter the most sophisticated of these labs (thereby developing some interesting case studies of "spiral" curricula for laboratory instruction).

One barrier to widespread adoption of this class of instructional labs has to do with the current cost of the particular type of single-photon detectors required; a histogram of ALPhA survey data regarding financial support of advanced laboratory instruction looks like a stretched exponential, which demonstrates that *minimal* ongoing investment is a common problem. Currently, it costs about $10k for the 4-detectors module purchased for these instructional labs by early adopters. So, ALPhA has been working with key vendors in the hopes that they might be convinced to make something more affordable available to the educational market. The positive response we have received means that these efforts to create a special product category with relaxed specifications, explicitly aimed at the educational market, are expected to have very significant impact by the time of the 2012 BFY conference, underscoring the importance of including (many) vendors in our discussions, as active participants in the conference, and in our ongoing efforts toward enhancing opportunities for laboratory instruction.

At the 2009 Topical Conference on Advanced Labs, twelve vendors brought commercially produced instructional experiments, greatly extending the number of available workshops to a total of 54 hands-on workshops on advanced lab experiments or advances in data acquisition and data handling. For the 2012 BFY lab conference, we want to hear ***from you*** about what experiments you would like to have this sort of hands-on experience with: so, instead of vendors bringing *products*, as at a traditional trade show, we will work with both you and them to set up appropriate instructional *experiments* that make use of their products. We also seek faculty and staff participants who might be able to *transport* their own new or improved instructional experiment, to share on site.

Broadly, the conference goals were that attendees should come away with:

- Knowledge of commercially available equipment appropriate for BFY labs
- A knowledge of, and ***hands-on experience*** with, contemporary or improved experiments and techniques
- A broader view of ***teaching strategies and pedagogy*** for the laboratory
- Methods for assessing student understanding in laboratory instruction, including, in particular, assessment of writing
- An understanding of the wide variety of ***curricula*** used for laboratory instruction
- Techniques for programmatic ***preparation*** for undergraduate research and for integration of undergraduate research with the instructional laboratory curriculum

In *preparation* for this major educational conference, there are many initiatives to work on. This summer we initiated the ALPhA Immersion Program, where instructors spend three full days, with expert colleagues on hand, learning the details of a single, key instructional physics experiment well enough to incorporate it into their teaching with confidence. All "sold out" and generated waiting lists (eleven different options for focused, multi-day training, with multiple offerings of some), demonstrating a high level of interest among instructors. The outcomes of these initial offerings will be shared at the BFY Conference, and we continue to **seek your suggestions** for future Immersion Program offerings. ALPhA is also in the early stages of constructing a travelling mentor program aimed at faculty/staff development relevant to advanced laboratory instruction. In addition, ALPhA has gathered data by launching its national survey regarding physics laboratory instruction beyond the first year of college, and as this data is analyzed the need to follow up will undoubtedly become clear. Through educational partnerships with the APS Forum on Education, the AAPT, PIRA, ComPADRE, the many vendors interested in laboratory instruction, the funding agencies **and you**, we have an opportunity to be a force for good.

Gabe Spalding of Illinois Wesleyan University, is President of the Advanced Laboratory Physics Association and Vice-Chair of the national AAPT Committee on Laboatories.

My Experiences at the Gordon Conference on Physics Research and Education 2010

Guangtian Zhu

In June 2010, I attended the Gordon Research Conference (GRC) on physics research & education in Mount Holyoke College. As a graduate student attending the GRC for the first time, I had a very pleasant experience. The conference helped in broadening my views about physics education and I strongly recommend that graduate students attend the conferences in this series that take place every two years.

My first impression of the GRC is that of a friendly environment for discussion of ideas. All the professors, researchers, graduate students and undergraduate students lived in the same building and ate together in the same dining hall. We all had lively discussion about our research and other things that brought us closer together during breakfast, lunch and dinner and it was easy for everyone on the table to join in the discussion. The GRC gave us a wonderful opportunity for networking. Just consider the number of people I had dined with during the whole conference–at least one hundred! No other conference has ever provided me such an opportunity to talk to so many professors, researchers and students about physics research and education. I am really grateful for the networking opportunity at the GRC and that is at least one compelling reason for why graduate students should go the GRC.

This GRC focused on experimental research, mentoring of students and labs in physics education. Some researchers discussed how the lab they had developed encouraged students to think about the physics principle behind the experiments. Other researchers discussed how students can participate in contemporary physics such as the Large Hadron Collider. These discussions at the GRC have given me a better perspective. Even my colleagues at the University of Pittsburgh (Pitt) benefited from what I learned at the GRC. For example, when the physics demonstrator at Pitt asked me about a lab setup, the first demonstration that came to my mind was the one we discussed at the GRC.

The speakers presenting at the GRC were mostly from the US but some were also from abroad. Some were from the top research universities such as Harvard and MIT while others were from liberal arts colleges such as Pomona College. Some speakers talked about labs and how students can benefit from them, some talked about physics education research while others discussed how to involve students in traditional physics research. The most memorable presentation for me was by Eric Mazur from Harvard University who talked about how to introduce students to contemporary physics via seminar-based instruction.

Last but not the least, the great food and the traditional lobster dinner added to the fun. The location of the GRC, the Mount Holyoke College, was beautiful.

Guangtian Zhu is a graduate student at the University of Pittsburgh. He is conducting research in physics education.

Physics Teacher Education Coalition

Section on Teacher Preparation

From the Editor of the Teacher Preparation Section

John Stewart

In this issue, two of the new PhysTEC sites, California State University Long Beach (CSULB) and Middle Tennessee State University (MTSU), discuss their plans for improving teacher preparation. CSULB serves an urban population and is recognized as a Hispanic-Serving institution. CSULB is already important in teacher preparation in California and hopes to increase the number of certified teachers with physics degrees. MTSU is located in central Tennessee and partners PhysTEC with the successful UTeach model.

This newsletter has featured many descriptions of the PhysTEC program since its initial funding. As someone who participated in the first set of PhysTEC sites, the description of the programs planned at CSULB and MTSU is striking. Elements such as the Teacher-in-Residence and Learning Assistants that were pioneered by PhysTEC are now mature, well-understood components. The sophistication of the new sites in recruiting though aggressive and innovative advertising is impressive. Also, it is gratifying that the idea that more physics majors can imply more highly qualified physics teachers has taken hold.

Our last article by Valerie Otero of UC Boulder completes the sequence of Robert Noyce Scholarship articles begun last newsletter. The Noyce program has been exceptionally useful in teacher preparation efforts at my own institution, the University of Arkansas, at many PhysTEC sites, and at numerous other institutions. This article discusses the University of Colorado's use of a Phase II Noyce to expand their very successful Learning Assistant Program and their use of the Noyce Master Teacher's Track to support their Streamline to Mastery program.

John Stewart is an assistant professor in the department of Physics at the University of Arkansas.

The CSULB PhysTEC Project

Chuhee Kwon
California State University Long Beach

California State University Long Beach (CSULB) was one of the five universities selected as new Physics Teacher Education Coalition (PhysTEC) sites to begin in Fall 2010. The primary goal of the CSULB PhysTEC project shared with the national PhysTEC project is to increase the number of highly-qualified students earning secondary school teaching credentials in physics.

PhysTEC is a joint project between the American Physical Society (APS) and the American Association of Physics Teachers, and is now funded by a five-year, $6.5-million grant awarded by the National Science Foundation in Fall 2009, as well as APS's 21st Century Campaign.

Background

CSULB is a large comprehensive university located in the Los Angeles metropolitan area serving a diverse student population. The total enrollment in Spring 2010 was 31,586 students with 10,577 identifying themselves as Latino/Latina, African American, or Native American. The Hispanic Association of Colleges of Universities formally recognizes CSULB as a Hispanic-Serving Institution.

CSULB prepares 6% of California's secondary science teachers and a large number of pre-secondary teachers. The teacher preparation credential program in California is a 5th year, or post-baccalaureate, program. To earn a teaching credential in California candidates need to take basic pedagogy courses and demonstrate subject matter competence via coursework (a major or a minor in the subject matter) or via examination (California Subject Examination for Teachers in their subject matter).

During the last three years, the average number of credentialed physics teachers graduating from CSULB is 3.5 teachers per year. Most of these candidates are not from our own undergraduate program, and we believe that is because of the lack of targeted effort to recruit the CSULB physics majors/minors/graduate students to the secondary teaching credential program.

The CSULB PhysTEC project is the collaboration between the Department of Physics and Astronomy and the Department of Science Education bringing the strength of two departments together with the common goal. The Department of Physics and Astronomy has revised introductory physics laboratories and curricula during the last five years with close attention to physics education research. The department has enlarged its efforts toward recruitment and retention via paid research experiences aimed at students early in their studies.

The Science Education Department is situated with the Physics Department in the College of Natural Science and Mathematics allowing close cooperation. The Science Education Department oversees the science credential program at CSULB, placing student in many area partner school districts. Also the Science Education Department has hosted several funded projects to support future science teachers including the NSF-Noyce Program. PhysTEC teachers will thus be able to take advantage of an already established support structure.

We believe building a physics teaching community that partners CSULB physics and science education faculties, high school teachers, physics students (in undergraduate, graduate, and credential programs) is important to the success of the project as well as for long-term sustainability.

Project Description

The CSULB PhysTEC project combines several components shown to be successful in the national PhysTEC project; a Teacher-in-Resident (TIR) and Learning Assistants (LA). The TIR is a local high school teacher recruited to be a partner in the project activities, as well as a mentor, a recruiter, and a co-instructor for new courses. The project plans to have a part-time TIR and to select a different teacher each year. Rod Ziolkowski from Whitney High School will be the TIR in the first year.

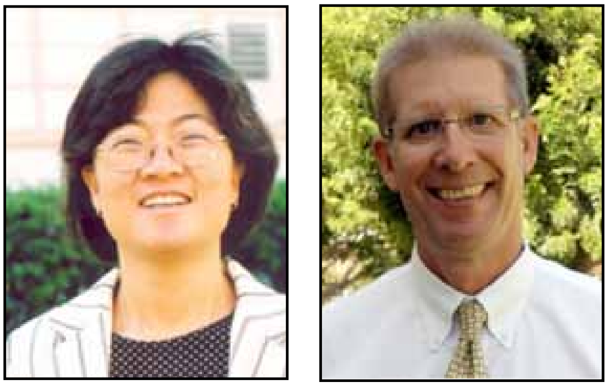
The Learning Assistant program involves undergraduate students in the introductory-level physics laboratory as junior teaching associates working with small groups. We will have a two-tier system for the LA program: the first experience as a LA is a required part of PHYS 390 coursework and senior LAs, selected after taking PHYS 390, will be paid from the grant.

Increasing the number of physics teaching credentials awarded is directly related to increasing the number of physics majors/minors and informing the students about high school teaching as a career option. Hence, a continuous recruiting effort will be an important part of the CSULB PhysTEC project. We plan to launch an aggressive advertising campaign to recruit students to physics majors/minors and to encourage them to consider physics teaching. Various events are formulated for different target groups: high school students via Physics Teacher Open House, freshmen in orientation events, transfer students from recruiting events in community colleges, students taking physics courses via classroom visitation by the TIR and advertising materials, and physics undergraduate/graduate students via advising. Participating students will be recognized as PhysTEC Scholars.

In addition to the recruiting effort, an early teaching experience course has been developed and approved. PHYS 390 *Exploring Teaching Physics* allows students to explore physics teaching in a supportive environment through tutoring, working in grades 9-12 classrooms, and assisting in the introductory level physics courses. PHYS 390 is already accepted as a part of the physics degree coursework, and we are pursuing the general education designation. Students from PHYS 390 who are interested in teaching or have potential will be recruited to the paid Senior LA positions. The Senior

LAs will act as junior teaching associates in the introductory labs, work in the Physics Issue Room, and help in maintaining and in setting up physics lecture demonstrations.

We will also offer a physics-specific teaching methodology section in PHYS 490 Special Topics. Students will collaboratively develop lesson plans, labs, demonstrations, and assessments related to a single topic that will be taught at the high school level. Each semester the course will delve into different topics. Students will be introduced to common student misconceptions in physics and research-based interactive pedagogical approaches to teaching. Another component of the course will have students access physics teaching resources from the National Science Digital Library and as a group develop an electronic portfolio of teaching resources. The students will leave the course with an electronic portfolio of physics teaching resources associated with a given topic. The TIR will be a co-instructor for the course. We anticipate that physics students (graduate and undergraduate) will likely find the course interesting and useful, and students in the credential program or high school teachers will find the course of interest and value. We are excited about PHYS 490 not only as a new course but also as another place to build and strengthen the physics teaching community in the Long Beach area.


(Left) Chuhee Kwon, (Right) Teacher-in-Residence Rod Ziolkowski.

The bi-annual open house led by the Department of Physics and Astronomy is another key component of the CSULB PhysTEC project. We plan to invite high school teachers with their students, to have a short seminar session with physics faculty, to tour the department research labs and facilities, and to do a simple hands-on activity for future classroom use. The first Physics Teacher Open House is planned to be on Oct. 16, 2010.

PhysTEC Scholars will receive continuing support including the paid Senior LA, the information about scholarships and funding opportunities for future teachers existing at CSULB (including Noyce Scholarship and paid summer internships at national labs and NASA), the opportunity to teach in the summer science camp organized by the Science Education Department, the opportunity to attend the professional meetings (AAPT and California Science Teachers Association), and monthly PhysTEC Scholars meetings.

The leadership team (three PIs, the TIR, and the coordinator) will work together to advise, mentor, and track the PhysTEC Scholars as they explore physics teaching and move into a teaching career. By building the physics teaching community that partners CSULB physics and science education faculties, high school teachers, physics students (in undergraduate, graduate, and credential programs), we expect that the PhysTEC Scholars will have a strong support group as new teachers, and they will become mentors to the next generation of physics teachers.

Our progress will be updated in the CSULB PhysTEC project website www.physicsatthebeach.com.

Chuhee Kwon is Professor of Physics at California State University Long Beach and co-directs the CSULB PhysTEC project with Profs. Galen Pickett (Physics) and Laura Henriques (Science Education).

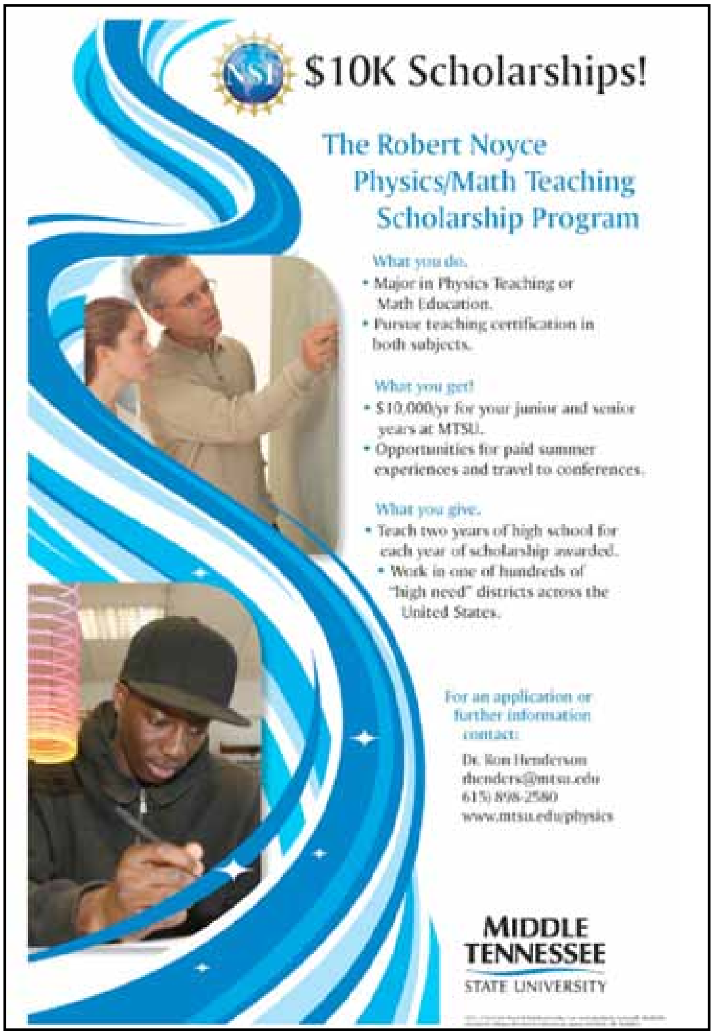
Physics Teaching Embraced at MTSU with the help of PhysTEC

Ron Henderson
Middle Tennessee State University

Physics teacher education is taking center stage at Middle Tennessee State University (MTSU), and being selected as one of three new comprehensive PhysTEC sites brings added momentum to the cause. MTSU is home to 24,000 students in the geographic center of Tennessee. The physics department graduates 5.4 majors each year, with many of these students continuing to graduate school in physics, astronomy, engineering, and medical physics. It would be safe to say that very few of our majors have become secondary teachers. In fact, over the past fifteen years the number of students that completed a major in physics and became endorsed to teach high school physics has totaled, well, zero. This is not a number of which we are proud; this number has become one of the primary motivators for our new emphasis in physics teaching.

Our Path

The department's journey toward the goal of graduating more high school physics teachers began two years ago with a challenge. In 2008 APS Director of Education and Diversity Ted Hodapp served as an external reviewer for the physics department and began a discussion of the nationwide need for qualified high school physics teachers. Ted suggested that our department was in a good position to be an instrument of change in this area, and we took that as a challenge. Our faculty members became energized at the prospect of making a significant difference in the education of high school students in our region and resolved to pursue an emphasis in physics teaching. Our first step, on Ted's advice, was to invite Gay Stewart from the University of Arkansas to visit. As PI of the PhysTEC site at Arkansas, Gay was able to share concrete steps that could be taken at MTSU to create an atmosphere that would encourage students to consider a career in physics teaching, as well as ways to make our curriculum more conducive to teacher preparation. Some of the steps were easy–learning more about the need for physics teachers, having a positive attitude toward teaching as a career choice, and getting more involved in national meetings focused on physics teaching. We found the community of PTEC and PhysTEC programs very helpful with all exhibiting a willingness to share experiences. Most of our current plan came from discussions that took place at regional and national meetings of PTEC and the AAPT. Other actions took more time and energy–securing a physics education research faculty line, infusing the curriculum with classes on physics pedagogy, and seeking external funding. During the first year, the department began sending faculty members to meetings related to physics teaching, designed several new courses for physics teachers, and won a Robert Noyce Scholarship Program grant. During the second year, we received board approval for a department concentration in Physics Teaching, pursued approval to hire a physics education research faculty member, and were selected as a new comprehensive PhysTEC site. In addition, our university was chosen to become a replication site for the UTeach teacher training program developed at the University of Texas at Austin; our local implementation is being called MTeach. We are now leveraging all these resources to build our physics education program.



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Where to Start?

Our department is pouring energy and resources into three primary areas this year to grow our teacher education efforts: programming, marketing, and assessment. The building blocks for our program are in place, but many of the specifics are being developed this year. New courses that were approved last year need to be fully designed, and further work on existing courses needs to happen as well. We are partnering with a marketing consultant to teach us how to reach more students from our local public schools as well as targeting existing science majors at our university. In addition, we are taking a serious look at how to measure the level of success from our efforts–both by counting graduates, interacting with them to glean information about their preparedness in content and pedagogical knowledge, and documenting attitudes toward science and teaching.

Hitting the Ground Running (Thanks, PhysTEC)

Program implementation is moving ahead quickly, thanks in large part to our partnership with PhysTEC. PhysTEC has provided mentoring and advice through both one-on-one discussions and workshops that involved other PhysTEC institutions. PhysTEC funding is making many of our curriculum improvements possible. Our program implementation involves developing new courses and redesigning existing courses, combining efforts of the education and science colleges through the MTeach initiative, and adding PER expertise to our department. The curriculum reform efforts began with the development of three new courses in the physics and astronomy department this year. In Physics Licensure, students will work in a combination seminar and independent study fashion to prepare for the Praxis II content exam. This course gives our future teachers the opportunity to compile a wide range of content knowledge from many physics courses and gain confidence in their ability to pass the licensing exam. Another first-time offering this fall is Concepts and Applications of Thermodynamics and Statistical Mechanics. Our approach in this course is to emphasize a conceptual understanding of thermodynamics by focusing on seminal ideas, with exercises designed to force the students to think about how they would teach the material. Our third new course for the year is The Teaching of Physics. This course has the two goals of introducing students to PER literature through a study of “what works” in physics education, and giving students the opportunity to put those ideas into practice. The seminar portion of the course will give our future teachers an overview of research-proven pedagogies in place in university classrooms, as well as successful programs used in high schools, including the Modeling pedagogy from Arizona State University. The second component of the course will require students to work as teaching assistants in introductory physics courses that employ inquiry-based techniques. Further curriculum improvements will happen during the summer of 2011 when our calculus-based physics sequence will be re-designed to employ an active learning environment with content and techniques borrowed from other successful programs. With these changes to our curriculum, we hope to create an improved environment for future physics teachers.

Add a Dose of UTeach … or MTeach

Our involvement with MTeach is most evident in what has historically been the education component of a science teacher’s program of study. The lines between what is education and what is science are now blurred, and the MTeach curriculum reflects this fact. Many of the MTeach courses will be taught by high school science and mathematics teachers that have joined the university faculty (Teachers in Residence (TIR) if you speak PhysTEC, or Master Teachers if you are more familiar with UTeach). Our department is particularly excited about the early teaching experience courses known as Step I and Step II. These one credit hour courses offer potential high school teachers a low-stress opportunity to experience the public school classroom as a teacher. Students will be involved first in observation and later as active participants in the classrooms of top elementary and middle school mentor teachers that will model best practices for the science classroom. We hope this experience will widen the pool of prospective high school teachers, especially among freshmen and sophomores. Students in a number of majors are required to take a year of physics, and quite a few become very interested in the department after that experience. However, because students tend to put off taking physics until their junior or senior years, they are often too close to graduation to consider a change in major after finding how great physics can be. The TIRs will also be involved in recruitment through visits to science classes on the university campus, and interacting with students in the physics department. We plan to leverage our physics TIR by inviting them to be full participants in all aspects of the department. The final piece in our implementation plan is the addition of a PER faculty line in the department. We are thrilled to have gained permission to fill a permanent tenure-track faculty line with an expert in PER. (Anyone interested in the position can apply online at mtsujobs.mtsu.edu, and contact the search committee chairman Dr. Vic Montemayor at vjm@mtsu.edu.)

Who Knew?

The second major area of emphasis for the year will be in marketing. Students that become involved in our department through classes or research projects tend to have positive experiences and be drawn to the physics major/minor. Evidence of this effect comes through an analysis of the first major declared by eventual physics B.S. recipients. Not many started as physics majors, and our graduates have often changed majors to physics after a positive experience with physics and astronomy faculty. We want to learn how to engage and interest students that have *not* experienced our department. This may include reaching out to high school juniors and seniors, and finding a way to connect to current university students that do not yet have concrete career plans. MTSU will be partnering with marketing consultant John Rice this year to help find a way to “get the word out” to each of these populations. John has experience designing marketing plans for other physics departments, and we want to tailor a message for our student base and our region of the country. Of course, having a great tag line is not a silver bullet for an advertising a program. We know that a successful program will involve a lot of work on our part, and we are ready for the challenge and excited at the prospect. Soon there will be on-line ads, banners, t-shirts, flyers, and other advertisements to inform others about initiatives in our department. We are currently trying to secure funding for a new science building to hold all the new majors.

The Proof is in the Pudding

Assessment may not seem to have the same importance as program implementation or marketing, but we are convinced that careful attention to what our majors say and do can provide an avenue for constant improvement. Our assessment plan begins with the straightforward task of administering nationally accepted conceptual content exams at the beginning, and again at the end, of the first semester of physics. Since the declared major of students in the introductory sequence is not a good indicator of their eventual degree, the test is given to all students in both the algebra-and calculus-based sequences. After the introductory sequence, much of the follow-up data is collected from declared majors during their senior year: by again administering conceptual content exams, by requiring participation in a scientific attitudes survey, and by evaluating students’ opinions regarding the quality of the department and their perceived level preparation for their career of choice. Another means of assess-

The first physics teachers that will graduate from Middle Tennessee State University as part of the PhysTEC program: (left to right) Paul Turner, Hilary Ball, and Dylan Russell.

ment centers on the required capstone thesis course and subsequent presentation. All physics majors must complete a year-long research project in their area of interest that culminates with a presentation to the faculty and students of the department. Many majors work with research faculty in our department, while others participate in REU programs throughout the country and abroad. Students in niche areas, such as physics teaching and medical physics, are allowed to conduct projects linked to their area of expertise. A physics teaching candidate might study an aspect of our inquiry-based pedagogy that would include quantitative assessment, or could produce inquiry-based lesson plans for topics that have not received widespread coverage in the literature. During the thesis presentation students are evaluated by department and visiting faculty. To further quantify performance on the capstone project, a rubric is being designed to facilitate measurement the quality of each written thesis. We hope that enough information can be collected from these sources to allow a critical look at our program and suggest avenues for improvement.

Let's Start Cooking

The first crop of physics teacher graduates is now in the pipeline. Our first teacher will graduate in three semesters (Hilary Ball), followed by two more the following year (Dylan Russell and Paul Turner). The department has laid a good foundation for a successful teacher education program by creating an atmosphere where physics teaching is valued, and by implementing a curriculum that will give students an opportunity to experience inquiry-based pedagogies while becoming content experts. In this manner, our graduates will be well on their way of constructing their own physics content knowledge as they become great physics teachers.

Ron Henderson is chairman of the Department of Physics and Astronomy at Middle Tennessee State University where he is co-PI of a NSF Robert Noyce Scholarship grant and PI of the MTSU PhysTEC grant. (rhenders@mtsu.edu)

A Synergistic Model of Educational Change

Valerie Otero, Michael Ross, Samson Sherman
University of Colorado, Boulder

The University of Colorado, Boulder (CU Boulder) has established an integrated model of educational change by leveraging funding from professional societies, national foundations, industry, and the University. Much of our work hinges on the nationally emulated Colorado Learning Assistant program (http://laprogram.colorado.edu/) together with the NSF-funded Noyce Fellowship program, which allows us to transform and study our large-enrollment, undergraduate courses so that they are more closely aligned with the findings of research in cognitive science and education. As a result, faculty from science, mathematics, and engineering have become involved in educational transformation and in recruiting and preparing students to become K-12 teachers[1].

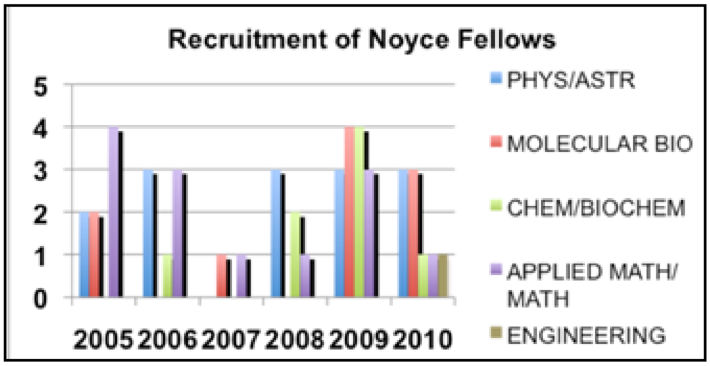
CU Boulder recruits teachers through the Colorado Learning Assistant (LA) program[2] and through the STEP I and STEP II courses of the CU-Teach curriculum[3] (part of the UTeach national replication effort). A critical part of our recruitment, preparation, and retention efforts is the Noyce Fellowship Phase I and Phase II programs[4], which provide support for LAs and CU-Teach students who have committed to teaching in high needs school districts. Finally, the Master Teacher track of the Noyce program provides crucial support for our *Streamline to Mastery* induction program[5], which seeks to retain teachers while preparing them for leadership positions in their districts and for participating in the national dialog on educational assessment and educational change.

At CU Boulder, approximately 85 undergraduate Learning Assistants (LAs) are hired each semester to work with Science, Technology, Engineering, Mathematics (STEM) faculty to transform large-enrollment, lecture-style courses so that they are more student-centered and interactive in 9 STEM departments. In 2009-2010, 40 classes were transformed using LAs including some upper division courses. All new LAs attend a special course in *Mathematics and Science Education* taught by an education faculty and an experienced K-12 teacher. These LAs comprise a pool of STEM majors from which we recruit new K-12 teachers. The Colorado LA program works closely with the Physics Teacher Education Coalition[6] of the American Physical Society and with the Science and Mathematics Teacher Imperative of the Association of Public and Land Grant Universities[7] who have similar goals. We received the Noyce Phase I grant in January 2005, at which time we restricted applicants to those who had served as LAs.

In 2008, we applied for and received a Noyce Phase II grant. With Noyce Phase II, all CU-Teach students recruited from the STEP I and II courses in addition to LAs became eligible for Noyce fellowships. Through our Noyce Phase II funding, we also embarked on a focused effort to increase diversity within the program by partnering with other diversity-focused programs on campus such as the McNiell program, the Miramontes Arts and Sciences Program, Education Diversity Scholars Program, Multicultural Engineering Program, and Partners in Science Education in the Community.

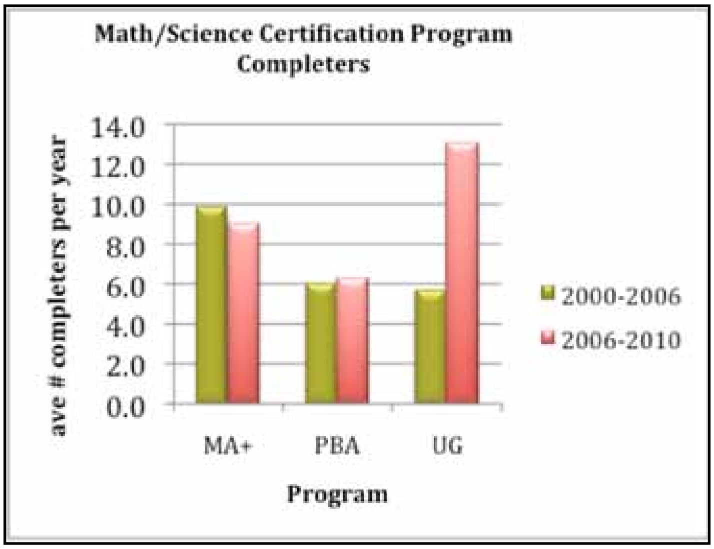
A unique element of the CU Boulder Noyce program is that all Noyce Fellows have the opportunity to work with STEM and education faculty and with K-12 teachers on discipline-based educational research and development projects often leading to publication and presentation at national conferences. For example, Noyce Fellows have worked on research involving students' model-building practices in magnetism[8], students' discourse in calculus[9,10], the development and deployment of photoelectric effect simulations[11], interactions between LAs and TAs in transformed settings[12], students' conceptions in molecular biology[13], the development and use of teaching guides for instructors, TAs and LAs in introductory chemistry, and the use and adaptation of the NSF-funded Physics and Everyday Thinking curriculum[14,15] in high schools.

Recruitment
Since the program began in 2005 we have recruited a total of 68 LAs to careers in teaching, 48 of whom applied for and were awarded Noyce Fellowships as shown in the figure above. Currently 12 of these teachers are teaching full-time in high-needs school districts mostly throughout Colorado, but some in other areas throughout the United States.



In order to track the increase in the number of teachers that result from the LA/Noyce program more broadly, we compare the average number of students completing math and science certification programs each year in three different teacher certification programs at CU: the Master's Plus certification program (MA+), the Post-Baccalaureate certification program (PBA), and the Undergraduate certification program (UG) before and after the LA/Noyce program started graduating its first certification students. The UG program is the program into which we recruit our LAs and Noyce Fellows. As is evident in the graph, the MA+ and the PBA programs stayed the same, the UG program increased dramatically from before and after we saw our first LA graduates.

Induction and Retention
The Streamline to Mastery induction program at CU Boulder is an



NSF-funded Teaching Fellow/Master Teacher track of the Noyce program. Our Streamline to Mastery professional development program is unique in that seeks to capitalize on the expertise of teachers toward the creation and implementation of a useful professional development program for themselves and for other teachers. The creation and implementation of the professional development program by the teachers themselves also serves as participant-driven professional development for these teachers leading to leadership identities and skills. The NSF Noyce TF/MT track provides salary supplements of $15,000/yr for teachers to participate for five years in professional development leading to mastery.

Currently, four physics and physical science teachers are participating in our program (they will begin the process of selecting the next cohort of eight teachers in Spring 2011). Two of the teachers are former LAs and Noyce Fellows from CU Boulder, the third has a Ph.D. in Biochemistry, and the fourth received a master's plus certification from a prestigious program at CU Boulder. The two former LAs received their master's degrees in Urban Education from a competitive program at the University of Denver. In addition, the Streamline to Mastery team consists of two graduate students in physics education research (both former high school physics teachers), four current Noyce Fellows (two undergraduate physics majors, one doctoral student in physics, and one undergraduate chemistry major), and one project principal investigator.

The Streamline to Mastery vision is that through strategic use of opportunities for professional development that draw on the skills that the teachers, graduate students, Noyce Fellows, and professors already have, we can develop expertise as a community that will lead to increased mastery of the content, of pedagogy, and of our own identities as agents of educational change. Like the LA program, the Streamline to Mastery program is an experiential learning program where all participants are working together to establish a greater understanding of our roles in educational change. At the same time, the evolving community provides a rich forum for Noyce Fellows to work directly with real, current teachers as they deliberate over daily features of their jobs including rewards, obstacles, challenges, and strategies for working with students and administrative issues. In addition, Noyce Fellows assist classroom teachers with their action research projects. We hypothesize that this opportunity provides superior, authentic teacher preparation for our Noyce Fellows while serving as a mechanism for establishing superior professional development for our Streamline to Mastery teachers. As such we are evaluating various aspects of the program internally and externally.

Participant Views of the Streamline to Mastery Program

In order to provide an accurate illustration of the Streamline to Mastery program, we offer statements made by the teachers themselves.

Teacher 1: Unquestionably, Streamline to Mastery has had a profound effect on my teaching practice and pedagogy. After a tough first year of teaching as the only physics teacher in our school, and coming in with a background in cell biology rather than physics, I'm not sure that I would have opted to continue teaching physics if I had not had the opportunity to join Streamline and take advantage of the many avenues for support and professional development to which I now have access. I am researching the effect on student growth (academic and social) of student-student mentoring experience. My high school students will be teaching physics to local elementary students in schools where science has been cut from the curriculum using a Learning Assistant-style model.

Teacher 2: In the Fall of 2008 I began teaching Physics and Chemistry in an urban high school in north Denver and I truly began to understand the amount of patience, multi-tasking, and compassion necessary to introduce science content to high school students. I quickly learned that teaching involves many ups and downs and several times each month I found myself asking, "why am I a teacher?" and "am I really making a difference?" I felt alone in these questions, because my colleagues rarely looked as though they struggled and seemed too busy to discuss their teaching experiences. However, when I began working with the Streamline to Mastery cohort I soon was comforted with a healthy dose of reality and optimism from three colleagues who also teach science in the Denver-Metro area as well as the University–based team. For the first time in my teaching career, professional development became personal; it was not about what someone else could "teach us" (that they deemed important), but rather was about critically reflecting on pressing issues within our own classrooms. At Streamline, we openly discussed challenges like district-mandated curriculum or engaging students who have had very negative science experiences.

Teacher 3: As a teacher in a small public school where I am the only 9th grade science teacher, it is easy to get swept up in the minutia and lose track of the big picture (and why I became a teacher in the first place–the students). The Streamline to Mastery program is an exciting opportunity to become a better science teacher, a leader and a change agent, which helps me feel grounded and puts everything back into perspective. This unique forum allows me and the other teachers to collaboratively explore various aspects of teaching and learning with other experts in science education. We have learned so much from each other by being able to share openly about our struggles and successes, analyzing our students' work to explore the concept of inquiry, and embarking on thoughtful action research to dive deeper into various aspects of my own teaching and learning. I anticipate growing and stretching my thinking as I continue to become a leader and a change agent in science education.

Teacher 4: At this point in my career I am required to attend certain meetings and trainings that are aimed at improving my teaching and thus improving student achievement. The meetings and training are sometimes helpful, encouraging and inspiring but other times they are discouraging and irrelevant to what really goes on in my classroom. What Streamline has done for me is create a space where the meetings are always helpful and relevant simply because we as teachers are part of the process of designing what works for us. I feel like my experience and ideas as an educator are valued. I have found that participating in action research in my classroom is challenging, yet rewarding, but more importantly it engages me as a teacher to analyze what is working in my classroom and what needs to be improved. Having ownership in my research is what makes it work.

Summary

The Noyce Fellowship and Noyce Streamline to Mastery programs at CU Boulder synergistically interface with the LA program, the CU Teach certification program, and with one another. By leveraging resources from multiple sources we have begun to establish a structure through which future teachers work with inservice teachers in ways that greatly benefit both. By bringing our graduate students into the mix, we have been able to bridge research and practice both for teacher preparation and for teacher professional development and retention.

(Endnotes)

1. V. Otero, S. Pollock, N. Finkelstein (in press), *American Journal of Physics*.

2. Funded by NSF grants #302134, #554615 and PhysTEC

3. Funded in part by the National Mathematics and Science Initiative

4. Funded by NSF grants #434144 and #833258

5. Funded in part by NSF grant #934921

6. http://www.colorado.edu/physics/EducationIssues/phystec/

7. http://www.aplu.org/NetCommunity/Page.aspx?pid=584

8. Otero, V., Jalovec, S.,* & Her Many Horses, I.* (2006, July). *Evolution of Students' model-building practices in an inquiry-based physics course*. Paper presented at the biannual meeting of the American Association of Physics Teachers, Syracuse, NY.

9. Spooner, K.,* Geist, A.,* Curry, J., Dougherty, A., & Nelson, M. (2007, January). *Learning Assistant research in the Applied Mathematics department*, Boulder, Colorado. Paper presented at the Joint Mathematics Meeting, New Orleans, LA.

10. Nelson, M. A., Geist, A.,* & Venturo, A.* (2008, January). *Noyce Fellows and Learning Assistants at CU*, Boulder. Presented at the Joint Mathematics Meeting, San Diego, CA.

11. McKagan, S. B., Handley, W.,* Perkins, K. K., & Wieman, C. E. (2009). *A research-based curriculum for teaching the photoelectric effect*, American Journal of Physics.

12. S. Stachurski, V. Lyman, V. Otero (2010, March) *Urban Teachers' Views of the Colorado Learning Assistant Program*, Presented at the Spring Colloquium Series, School of Education, University of Colorado, Boulder.

13. Klymkowsky, M. W., Gheen, R.,* & Garvin-Doxas, K. (2007). Avoiding reflex responses: *Strategies for revealing students' conceptual understanding in biology*. In L. McCullough, J. Hsu & P. Heron, (Eds.), 2007 Physics Education Research Conference Proceedings. Melville, NY: AIP Press, 3-6.

14. F. Goldberg, S. Robinson, and V. Otero, *Physics and Everyday Thinking* (It's About Time, Herff Jones Education Division, Armonk, NY, 2007). Funded in part by NSF grant #096856

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Michael Ross is a doctoral candidate in science education at the University of Colorado, Boulder. After teaching high school physics for 5 years, he turned his attention to graduate school to study how culture, race, and power interact with students' opportunities to learn physics in American secondary schools.

Browsing the Journals

Carl Mungan

- Beginning with the September 2010 issue of *The Physics Teacher* (http://scitation.aip.org/tpt/), one article per issue will be selected and supplemented with an interactive computer model developed using the Easy Java Simulations (EJS) code with the assistance of Wolfgang Christian. In this first issue, the article selected is "Calibration of a Horizontal Sundial" and includes three EJS models which illustrate the geometry of a north-oriented sundial's shadow for different latitudes and times of day. In the same issue, be sure to read the enlightening Letters to the Editor by John Mallinckrodt and by Eugene Mosca, reminding us that force is not equal to the derivative of momentum for a system of "variable mass."

- *American Journal of Physics* (http://scitation.aip.org/ajp/) is also selecting one article per issue to supplement with EJS models. The October 2010 issue chose "A close examination of the motion of an adiabatic piston," which includes a link to a molecular dynamics simulation in which a box is partitioned by an insulated piston that is jostled back and forth by two different Lennard-Jones gases in the two sides of the box.

- The September 2010 issue of *Physics Education* has a great way to demonstrate Poisson's spot in class. All you need is a laser pointer and a pin with a round head, which is much simpler than the typical setup using collimation optics and a video camera. The September issue of the *European Journal of Physics* discusses in "A thermal paradox" the question of which reaches a higher steady-state temperature: a thin or a thick plate of the same material uniformly illuminated on one face by a constant beam of light? Theory is compared with experimental results. Both journals can be accessed at http://iopscience.iop.org/journals.

- A couple of articles caught my eye in the October 2010 issue of the *Journal of Chemical Education* (http://pubs.acs.org/journal/jceda8). Page 1039 quantifies the hearing risk associated with exploding balloons containing hydrogen gas in class. Then on page 1071, a mechanical apparatus is discussed to model the Morse potential for anharmonic diatomic bonds.

- The *Journal of Science Education and Technology* recently published online an article entitled, "How the Discovery Channel Television Show Mythbusters Accurately Depicts Science and Engineering Culture." See http://www.springer.com/education+%26+language/science+education/journal/10956.

- You don't rate a *chili pepper* on RateMyProfessors.com? Well, maybe you or a colleague is a pizza slice or a *harmonica* instead! Check out the proposed new icons in the *Chronicle of Higher Education* at http://chronicle.com/article/RateMyProfessorsAppearance-com/124336/.

Web Watch

Carl Mungan

- Hendrik Ferdinande of Belgium wrote to correct my statement in the *Summer FEd Newsletter* that the *Institute of Physics* (IOP) is a European counterpart of the AIP. He suggested that a better counterpart would be the *European Physical Society* (EPS) http://www.eps.org/about-us, the IOP being only one member society (for the UK and Ireland) of the EPS.

- It's the fiftieth anniversary of the laser! A timeline of its history can be found at http://www.photonics.com/linearcharts/default.aspx?ChartID=2. Also be sure to visit LaserFest's website at http://www.laserfest.org/ and IOP's collection of review articles at http://iopscience.iop.org/0034-4885/page/Celebrating 50 years of the laser.

- I have heard some positive comments about http://www.khanacademy.org/, whose mission is to provide a large databank of short instructive videos that teach concepts in math, science, and finance.

- Lately I have been learning how to numerically solve partial differential equations using the Method of Lines. A fantastic primer, together with detailed MatLAB code, can be found at http://www.scholarpedia.org/article/Method_of_lines.

- A Mathematica notebook which calculates the magnetic field at any point in space due to a set of coaxial coils (not necessarily all identical) can be downloaded from http://www.phy.duke.edu/research/photon/qoptics/techdocs/.

- A useful assortment of educational links on astronomy, spaceflight, and electromagnetism can be found at http://www.phy6.org/readfirst.htm.

- Have you ever been exasperated trying to delete a blank page at the end of a Word document, particularly just after a table? I found http://sbarnhill.mvps.org/WordFAQs/BlankPage.htm to solve the problem for me.

- A great resource for advising and mentoring students about physics careers can be found on comPADRE at http://www.compadre.org/careers/. If you have hallway monitors in your physics building, you may also wish to put up APS's InSight slide show to interest undergraduates in physics, available for download at http://www.aps.org/careers/insight/index.cfm.

- A couple of interesting presentations from AAPT's summer meeting in Portland, OR include an explanation of quantum mechanical decoherence at http://visualquantum.net/DecoherenceDemo/ and a talk about how a diver with zero angular momentum can nevertheless reorient his body in midair at http://feynman.poly.edu/dibartolo/talks/Portland/.

- Also mentioned at the meeting were: a nifty presentation tool at http://prezi.com/, sharing photos using http://www.flickr.com/, and making your computer documents available from any web browser via https://docs.google.com/.

- A website rich in resources devoted to "clickers" (student remote controls used to answer computer-projected multiple-choice questions in class) is http://www.cwsei.ubc.ca/resources/clickers.htm.

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