**Summary: 1997 Conference of Physics Department Chairs**

# "Undergraduate Education in Physics: Responding to Changing Expectations"

**Sponsored by the American Physical Society and the American Association of Physics Teachers**

**May 9-11, 1997, American Center for Physics, College Park, MD**

**Roger D. Kirby and Jerry P. Gollub, Co-chairs**

**Steering Committee**: Peter J. Collings, Stephen D. Ellis, Judy Franz, Anthony M. Johnson, Bernard V. Khoury, Kenneth S. Krane, Daniel J. Larson, John Mateja, Mary Beth Monroe, Lawrence R. Sulak

## Background and Purpose

Undergraduate Physics programs are under increasing pressure from university and college administrations, industry and funding agencies to better educate and train our students at all levels, from our introductory courses to our advanced senior level courses. The expectations for our programs have changed, and evidence is mounting that they need revitalization; in particular, most programs have a small number of majors with respect to faculty size, and many faculty and students have expressed dissatisfactions with their experiences, particularly in the introductory courses.

The results of research on physics education and on the problem of attracting and retaining students from varied backgrounds (including women and minorities) imply that many of our programs can be improved by:

- Incorporating the results of physics education research (and other relevant work) in the classroom, laboratory, discussion groups, and electronically;
- Encouraging mentoring relationships, especially via research participation with faculty members;
- Reaching out to students who do not major in the sciences;
- Providing flexible programs that connect physics to other disciplines and professions.

The recent NSF report "Shaping the Future" recommends that each science department "Set departmental goals and accept responsibility for undergraduate learning, with measurable expectations for all students; offer a curriculum engaging the broadest spectrum of students; use technology effectively to enhance learning; work collaboratively with departments of education, the K-12 sector and the business world to improve the preparation of teachers (and principals); and provide, for graduate students intending to become faculty members, opportunities for developing pedagogical skills."

This meeting was intended to help Department Chairs provide the leadership needed to advance their programs along these lines. The program included invited talks, breakout sessions, and informal opportunities for participants to benefit by sharing ideas and experiences informally chairs from other institutions. Some participants provided brief summaries of innovations from their own institutions.

## Overview

This document contains the Conference Program, brief summaries of many of the invited talks, and reports of the breakout discussion groups. We also include the titles of the contributed innovations.

Improvements in undergraduate education should take advantage of the results of physics education research. There is now considerable evidence that so-called *active engagement methods* offer the possibility of substantially better student learning and attitudes. Eric Mazur (Harvard), Edward F. Redish (Maryland), and Lillian McDermott (Washington) informed us about this research, and provided hands-on experiences to show us how it can be done.

Since physics as a profession cannot accommodate large numbers, it is clear departments wishing to attract more students must actively work to build links to other professions and disciplines. Examples of ways in which some departments are doing this were provided by Joseph Pifer (Rutgers), Vijendra Agarwal (Moorehead State), and Lyle Roelofs (Haverford).

Substantial curricular innovations at the introductory level in large departments were discussed by David Campbell (Illinois) and Louis Bloomfield (Virginia). Overviews of programs at the National Science Foundation were provided by Duncan McBride and Bob Eisenstein.

Successful undergraduate programs that include women and minorities require substantial attention to mentoring and advising. James Stith, Neal Abraham, and Priscilla Auchincloss discussed successful programs that can make a real difference in this area. Stewart Smith (Princeton) showed how a universal requirement of undergraduate research can succeed with students having a wide range of abilities and interests.

Many other issues were discussed through breakout sessions of about 20 participants. If undergraduate education is to be taken seriously, *reward systems for faculty members* should reflect an institutional commitment in this area. Our concerns must include *courses for non-majors*. We need to test our efforts by becoming better informed about *student assessment and measurement of learning.* And we need to utilize *undergraduate research* more frequently as a way of facilitating student intellectual and personal development.

## Conference Program

### A. Major Issues in Undergraduate Physics Education

Roger Kirby , University of Nebraska — Moderator

1. *"Physics at the Crossroads: Innovation and Revitalization in Undergraduate Physics - Plans for Action"*
   Robert C. Hilborn, Amherst College

2. *"NSF and the Future of Undergraduate Physics*
   Duncan McBride, Division of Undergraduate Education
   National Science Foundation

**B. Physics Education Research and Active Engagement Methods**

Isaac Abella, University of Chicago — Moderator

1. *"Physics: The Classics Department of the 21st Century?"*
   Eric Mazur, Harvard University

2. *"New Models of Learning and Teaching"*
   Edward F. Redish, University of Maryland

3. *"Bridging the Gap Between Teaching and Learning: the Role of Research"*
   Lillian McDermott , University of Washington

4. Tutorials: (a) Lillian McDermott, and staff; (b) Edward F. Redish

**C. Flexible Curricula for Diverse Career Opportunities**

Kenneth Krane, Oregon State University — Moderator

1. *"Tripling the Number of Physics Majors at a Research University"*
   Joseph Pifer, Rutgers University

2. *"Physics Majors of the Future? One Flexible Curriculum Approach"*
   Vijendra Agarwal, Moorhead State University

3. *"Preparing Physics Majors for Secondary-Level Teaching: The Education Concentration in the Haverford College Physics Program"*
   Lyle Roelofs, Haverford College

**D. Curricular Innovations**

Mary Beth Monroe, Southwest Texas Junior College — Moderator

1. *"Parallel Parking an Aircraft Carrier: Re-engineering the Calculus-Based Elementary Physics Sequence at Illinois"*
   David Campbell, University of Illinois

2. *"How Things Work: a Novel Approach for Teaching Physics to Non-Scientists"*
   Louis Bloomfield, University of Virginia

3. *"Innovations in Undergraduate Education"*
   Contributions by various departments represented at the meeting

**E. Breakout Sessions**

1. *Reward Systems for Faculty*

*2. Flexible Curricula*
*3. Courses for Non-Majors*

**F. Evening Session**

Douglas K. Finnemore, Iowa State University — Moderator

1. *Breakout Session Summaries*

2. *"The Future of Physics: A View from Washington"*
Robert Eisenstein, National Science Foundation

**G. Undergraduate Research and Mentoring**

John Mateja, Department of Energy — Moderator

1. *"Achieving Ethnic Diversity"*
James Stith, Ohio State University

2. *"Mentoring the Whole Life of a Physics Major: From Recruiting and Introductory Classes to Research and Careers"*
Neil Abraham, Bryn Mawr College

3. *"Special Issues for the Retention of Women and Minorities"*
Priscilla Auchincloss, University of Rochester

4. *"Undergraduate Independent Research at Princeton"*
A. J. Stewart Smith, Princeton University

**H. Breakout Sessions**

*4. Women and Minority Student/Faculty Recruitment and Retention*
*5. Student Assessment and Measurement of Learning*
*6. Undergraduate Research: Making it Better*

*Breakout Session Summaries*

*Closing Remarks*
Roger Kirby, University of Nebraska

## A.1. Physics at the Crossroads: Revitalizing Undergraduate Physics

Robert C. Hilborn
Amherst College, Amherst, MA 01002-5000

Why is this conference focusing on undergraduate physics education? There are two threads: First, two recent reports, *Shaping the Future, New Expectations for Undergraduate Education in Science Mathematics, Engineering, and Technology*[1] from the National Science Foundation and *From Analysis to Action, Undergraduate Education in Science, Mathematics, Engineering and Technology*[2] from the National Academy of Sciences both exhort the higher education community to reform and revitalize undergraduate science education. The primary imperative of the *Shaping the Future* report is that

"...all students [should] have access to supportive, excellent undergraduate education in SME&T [science, mathematics, engineering, and technology], and all students [should] learn these subjects by direct experience with the methods and processes of inquiry."

"All" in this case means not only our physics majors, but also students in our service courses, including engineers, pre-medical students, and pre-service teachers. "All" also means that we need equal access to SME&T education for women, minorities, and others underrepresented in the scientific community. "Direct experience [with] ...inquiry" means that passive lectures alone are not appropriate for teaching undergraduates.

The second thread begins with a conference sponsored by the American Association of Physics Teachers (AAPT). In September, 1996 a group of 22 physicists met with representatives of the undergraduate reform movements in chemistry, mathematics, and engineering to discuss a possible reform effort in physics. The resulting report "Physics at the Crossroads" has been widely distributed in the physics community with feedback indicating general support for the goals stated in that report: Development of an infrastructure (including web-based dissemination of ideas and materials, case histories of successful departmental reforms, and so on) to support the notion of continuous, nation-wide reform in undergraduate physics.

A quick review of the statistics indicating a steady decline in the number of physics majors[3] and a survey[4] of several thousand introductory physics students' conceptual understanding indicates that there are reasons for serious concern, but also indications for optimism because "interactive-engagement" methods of pedagogy seem to improve both students' conceptual understanding of physics, a goal of all introductory physics courses, and students' attitudes toward physics.

How will we know when undergraduate revitalization has succeeded? I suggest the following criteria:

1. More undergraduate students find physics a challenging but hospitable subject.
2. All physicists view teaching as an on-going scholarly activity.
3. We all celebrate the wide range of activities and careers that make up the practice of physics.

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[1] *Shaping the Future, New Expectations for Undergraduate Education in Science Mathematics, Engineering, and Technology*, Advisory Committee to the NSF Directorate for Education and Human Resources. (1996). The report is accessibel through the NSF web site: www.nsf.gov (The report is in the file nsf96139.txt.)

[2] *From Analysis to Action, Undergraduate Education in Science, Mathematics, Engineering and Technology* (National Academy Press, Washington, D.C., 1996). The National Academy Press web site is at www.nap.edu.

[3] Patrick J. Mulvey and Elizabeth Dodge, "*1995 Bachelor's Degree Recipients Report*," AIP Publication No.

R211.27. (American Institute of Physics, Woodbury, NY, 1996).
[4] Richard R. Hake, *"Interactive engagement vs. traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses,"* submitted to Am. J. Phys. (1997). *"Interactive-engagement methods in introductory mechanics courses,"* preprint. *"Evaluating Conceptual Gains in mechanics: A six-thousand student survey of test data,"* Proceedings of the International Conference on Undergraduate Physics Education, University of Maryland, College Park, MD (1996).

## B.1. "Physics: The Classics Department of the 21st Century?"

Eric Mazur
Harvard University, Cambridge MA 02138

Eric Mazur's contribution began with a video showing the U.S. Senate Majority Leader discussing how he wasted his time studying physics, shown in order to demonstrate the urgency of improving our students' experiences in physics. He then proceeded to demonstrate the use of peer instruction, which actively involves the students in the teaching process, can easily be adapted to fit individual lecture styles, and makes physics not only more accessible for students but also easier to teach. The method has been shown to improve students' conceptual learning at a wide variety of institutions.

This work is described in detail in *Peer Instruction* by Eric Mazur (Prentice Hall, 1997).

## B.2. New Models of Learning and Teaching

Edward F. Redish
University of Maryland, College Park 20742-4111

We are being asked to change the way we teach. Instead of only training top research scientists (and trashing the rest) we are now being held responsible for adding value to all of our students. What we have to offer our students is a good understanding of the physical world and powerful, complex problem solving skills. To help more of our students reach these goals, we need to help them develop a good functional understanding of physics -- to build a coherent mental model. Few introductory physics students currently do this successfully. If we are to be more effective with more of our students -- especially with those who do not resemble research physicists, we need to understand how they think. This talk reviews some general principles, built from understandings developed in cognitive psychology and education, that can help us to understand some of the "strange" responses we often get from our introductory students. We learn such principles as:

- Learning is better described as a growth than a transfer.
- Cognitive response is context dependent.
- Transfer is non-trivial -- even among isomorphic situations.
- It isn't enough to get them to know the right answer, they have to also get rid of the wrong answers.

- Students frequently can solve complex algorithmic problems without having a good understanding of the physics.

In this talk, we present a number of results from research into student understanding in introductory physics, showing how these cognitive principles are reflected in student performance in real classrooms. New methods of evaluating student understanding are discussed and applied to some innovative instructional models.

The slides from this talk are available on the web at URL *http://www.physics.umd.edu/rgroups/ripe/talks/chairs/*

Related talks, papers, and information may be found at *URLs http://physics.umd.edu/rgroups/ripe/efr/redish.html* (Redish homepage) and *http://www.physics.umd.edu/rgroups/ripe/perg/* (University of Maryland at College Park, Physics Education Research Group homepage)

## B.3. Bridging the Gap between Teaching and Learning: The Role of Research

Lillian C. McDermott
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Most physics instructors are aware that only a very few students (< 5%) in an introductory university physics course will major in the subject and the number who go on to graduate study is many times smaller. Not all realize, however, that we are in a much better position today than ever before to increase the likelihood that the study of physics will contribute to the intellectual growth of our students. This possibility exists both for our majors and for the much larger number of students who take the subject to fulfill a professional or distribution requirement. The most significant difference between the present situation and previous reform efforts is the growing body of knowledge about student understanding in physics. Research on the learning and teaching of physics is a relatively new field for scholarly inquiry.

During the past two decades, a steadily increasing amount of research on the learning and teaching of physics has provided a rich resource for the development of curriculum.[1] As implemented by the Physics Education Group at the University of Washington, the process of using research to guide curriculum development has three interrelated parts: (1) conducting systematic investigations of student understanding; (2) applying the results in the development of instructional strategies to address specific difficulties; and (3) designing, testing, modifying, and revising the materials in a continuous cycle on the basis of classroom experience with the target population.[2]

Investigations conducted among introductory physics students indicate that the gap between what is taught and what is learned is much greater than most instructors realize. Evidence from research indicates that, on certain types of qualitative questions, student performance is essentially the same: before and after instruction, in calculus-based and algebra-based physics, with and without standard laboratory, with and without demonstrations, in large and small classes, and regardless of the proficiency of the lecturer.[3]

In a typical introductory course, securing the intellectual engagement of students is a challenging task. To promote active learning, the Physics Education Group is developing *Tutorials in Introductory Physics*, a set of instructional materials that supplement, but do not replace, the lectures and textbook through which physics is traditionally taught.[4] The tutorials comprise an integrated system of pretests, worksheets, homework assignments, and course examinations. The pretests are usually administered after the material has been covered in lecture and always before the related tutorial. They inform the instructors about the level of student understanding and help the students identify what they are expected to learn in the tutorial session that they will attend that week.

During a tutorial session, 20 - 24 students work in collaborative groups of three or four. They proceed step-by-step through the worksheets that provide the structure for the tutorial. The worksheets consist of carefully sequenced tasks that guide students through the reasoning needed to develop a sound qualitative understanding of important concepts. The tutorial instructors do not lecture but ask questions designed to help students find their own answers. Tutorial homework assignments help students reinforce and extend what they have learned. All course examinations contain questions based on the tutorials. The tutorial system is tightly linked to a required graduate teaching seminar in which ongoing preparation of the tutorial instructors takes place on a weekly basis.

Many of the tutorials are expressly intended to target conceptual and reasoning difficulties that have been identified through research. In designing a tutorial sequence, we frequently employ an instructional strategy that involves a conceptual conflict. The procedure can be summarized as a series of steps: *elicit*, *confront*, and *resolve*.[5] One effective way of eliciting a known difficulty is to have students commit to a prediction before making an observation. The contradiction between a prediction and subsequent observation provides an opportunity to help students recognize an underlying misconception or inconsistency in reasoning. The tendency to make certain kinds of errors is often elicited by the pretest and tutorial worksheet. The tutorial and associated homework engage students actively in confronting and resolving specific difficulties that impede the development of a functional understanding of the material.

The role of the instructor is to help students by asking questions, rather than by simply giving answers. To teach in this way requires a deep understanding of the subject matter, knowledge of the intellectual state of students, and skill in asking appropriate questions. Most of the tutorial instructors are graduate Teaching Assistants (TA's) enrolled in the physics Ph.D. program. The rest are undergraduate physics majors, M.S. students, post-doc volunteers and a few faculty.

Preparation of the instructional staff takes place weekly in a required graduate teaching seminar. It is well known that most instructors tend to teach as they have been taught. Therefore, the seminar is conducted on the same material and in the same manner as the tutorial sessions. The participants go through the same sequence of activities as will the undergraduates later in the week.

At the beginning of the seminar, the participants take the pretest that was administered earlier in the day in the introductory course. Data from the pretests indicate that graduate students often have some of the same conceptual and reasoning difficulties as undergraduates.[6] The evidence demonstrates that advanced study in physics does not necessarily promote the development of a functional understanding of introductory topics. After taking the pretest, the participants examine the student pretests and try to identify common errors. Working collaboratively in small groups, they then go through the tutorial worksheets step-by-step. Experienced TA's engage the seminar participants in the same type of instruction through questioning that they will be expected to use in the tutorial sessions. Discussions of appropriate instructional strategies for addressing student difficulties arise naturally in this setting.

The tutorials can also be used to enrich student learning in institutions varying greatly in size and mission.[7] The instructional program that has been described is only one of several ways. The important feature that these have in common is the active involvement of the student at a sufficiently deep intellectual level that meaningful learning can occur. We have found that the tutorial system is particularly well-suited to the needs and constraints of a research-oriented physics department. It makes possible some degree of individualized instruction for students in large classes and provides a structure for faculty whose teaching assignments may rotate frequently. The tutorials are not as dependent as some methods on the charismatic qualities of a particular instructor. The tutorials, which are heavily dependent on the preparation of teaching assistants, provide both a strong incentive and an excellent environment for the rigorous preparation of teaching assistants.

For cumulative improvement of physics instruction to occur, individual efforts based on trial and error will not suffice. As is the case with most other academic aspects of university life, scholarly inquiry should play an important role. There is a need for ongoing, systematic investigation into the nature of student difficulties throughout the physics curriculum but especially in introductory courses. These contributions to the research base should not be limited to the identification and analysis of difficulties but should also include descriptions of instructional strategies that have been demonstrated to be effective. If experience has shown that certain methods appear not to work, then this information should also be reported. Relatively little attention has been directed toward assessment of the effect of specific instructional strategies on student learning. It is necessary to examine the intellectual impact on students and to ascertain in a rigorous manner whether the use of a particular instructional strategy brings about a real gain in student learning. This type of research can only be conducted by physicists who have thought deeply about the subject matter, who have had experience in teaching the material, and who are willing to listen carefully to students as a starting point for bridging the gap between teaching and learning.

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[1] A comprehensive list of references on research in physics education will be available in a Resource Letter for the *American Journal of Physics* that is being prepared by L.C. McDermott and E.F. Redish.

[2] For examples of this process as implemented by the Physics Education Group, see L.C. McDermott and P.S. Shaffer, "*Research as a guide for curriculum development: An example from introductory electricity. Part I: Investigation of student understanding,*" Am. J. Phys. **60**, 994-1003 (1992); Printer's erratum to Part I, ibid. **61**, 81 (1993); P.S. Shaffer and L.C. McDermott, "*Research as a guide for curriculum development: an example from introductory electricity, Part II: Design of instructional strategies,*" Am. J. Phys. **60**, 1003–1013 (1992); L.C. McDermott, P.S. Shaffer, and M.D. Somers, "*Research as a guide for teaching introductory mechanics: An illustration in the context of the Atwood's machine,*" Am. J. Phys. **62**, 46–55 (1994); T. O'Brien Pride, S. Vokos, and L.C. McDermott, "*The challenge of matching learning assessments to teaching goals: An example from the work-energy and impulse-momentum theorems,*" to appear in the *American Journal of Physics*; and K. Wosilait, P.S. Shaffer, and L.C. McDermott, "*Research a guide for the development and assessment of curriculum: An example from Light and Shadow,*" to be submitted to the *American Journal of Physics*.

[3] For examples of research in support of these statements, see, in addition to Ref. 2, L.C. McDermott, "*Millikan Lecture 1990: What we teach and what is learned—Closing the gap,*" Am. J. Phys. **59**, 301–315, 1991.

[4] L.C. McDermott, P.S. Shaffer, and the Physics Education Group at the University of Washington, *Tutorials in Introductory Physics*, to be published in a preliminary version in 1997. For discussions of specific tutorials, see the articles in Ref. 2.

[5] See Refs. 2 and 3.

[6] See the last three articles in Ref. 2.

[7] For discussion of the use of *Tutorials in Introductory Physics* at other institutions, see the last two articles in Ref. 2.

# B.4.(a) Tutorials in Introductory Physics†

## Examples from Electric Circuits and Geometrical Optics

Lillian C. McDermott, Paula Heron, Stamatis Vokos, Karen Wosilait, with Amy Liu

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Two of the classroom sessions that followed the three plenary talks were conducted by Lillian C. McDermott and the Physics Education Group. The purpose was to illustrate how the tutorials described in one of the talks can promote the intellectual engagement of students.[1] In each workshop, the participants worked through a tutorial from *Tutorials in Introductory Physics*, a set of research-based instructional materials developed by the group to supplement the lectures and textbook of a standard introductory course. The workshops were conducted in the same way as the undergraduate tutorial sessions and the graduate teaching seminars in which TA preparation at the University of Washington takes place. The participants worked in small groups on tutorial worksheets designed to address conceptual and reasoning difficulties identified through research.

The tutorial *Electric Circuits* guides students through the process of constructing a conceptual model for electric current from direct experience with simple circuits consisting of batteries, bulbs, and wires. The observations they make form the basis for a scientific model that can be used to predict and explain the behavior of simple electric circuits. In the tutorial *Light and Shadow*, students make observations using bulbs, masks, and screens. They use the ideas developed in this context to account for various phenomena, such as the formation of images and shadows due to extended sources. The role of research in the development of these tutorials has been described in articles.[2]

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1† L.C. McDermott, P.S. Shaffer, and the Physics Education Group at the University of Washington, Tutorials in introductory Physics, to be published in a preliminary edition in 1997.

1 Plenary Talk: Bridging the Gap Between Teaching and Learning: The Role of Research

2 L.C. McDermott and P.S. Shaffer, "*Research as a guide for curriculum development: An example from introductory electricity, Part I: Investigation of student understanding,"* Am. J. Phys. **60**, 994-1003 (1992); Printer's erratum to Part I, ibid. **61**, 81 (1993); and P.S. Shaffer and L.C. McDermott, *"Research as a guide for curriculum development: An example from introductory electricity, Part II: Design of instructional strategies,"* Am. J. Phys. **60**, 1003-1013 (1992); K. Wosilait, P.S. Shaffer, and L.C. McDermott, "*Research as a guide for the development and assessment of curriculum: An example from Light and Shadow*," to be submitted to the *American Journal of Physics.*

## C.1. Tripling the Number of Physics Majors at a Research University

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In the undergraduate physics programs at many colleges and universities the only students deemed worthy of being physics majors are those whose ability, motivation to work, and interest in physics would be adequate to get them admitted to a graduate program, preferably at one of the top schools. Students of lesser ability are ignored. Other high ability students who might be interested in physics, but not as a career, are subtly, or not so subtly, discouraged from majoring in physics. Yet in an increasingly technical society there is a far greater need in a broad range of occupations for scientifically literate college graduates than there is for more Ph.D.s desperately wanting to be physics or astronomy researchers, but forced to grudgingly seek employment elsewhere.

In this talk I outline how we have broadened our program to encompass non-traditional physics majors with a greater breadth of interests and how we consequently have seen the number of physics majors triple to 45 graduates in 1997. Our approach has been to introduce a variety of options with widely different math and physics requirements:

Professional Option -- a standard no-holds-barred sequence of courses intended to prepare students for graduate school.

Five Year Engineering Option -- a five-year program leading to dual degrees in physics (BA) and engineering.

General Option -- a liberal arts (BA) degree with maximal flexibility and minimal specifically required courses for pre-medical students, pre-law students, high school teachers, and students with no particular career goal in mind but who are attracted to a science major that gives them the flexibility to try out a variety of different fields or possibly double major.

Applied Option -- a BS degree that emphasizes a breadth of technical knowledge rather than narrow specialization and is designed for students who do not want to pursue a Ph.D., but who are interested in a job in some applied area or possibly a Masters degree .

Introducing a flexible curriculum is not enough to guarantee an influx of physics majors; advising is an even more important factor. Students who are unsure about their career goals are easily discouraged by indifferent, inaccurate, or hard-to-get advising. The problem is compounded by numerous options. Our advising system uses careful written documentation of the requirements, an e-mail alias reaching all majors and touch-tone registration so that an advisor does not spend time answering routine questions or approving class schedules. This frees time for more substantial questions such as career options. We find the most effective way to recruit physics majors and provide meaningful advice is at the first meeting with a student interested in majoring in physics. Such students frequently drop in without an appointment, but even if the student's interest seems somewhat tenuous, we find it essential, if at all possible, to immediately take the time - 15 minutes or more - to explore the student's interests, outline the career opportunities, help him or her choose the appropriate option, and to give the appropriate written material. This is the ideal time to discuss the advantages of getting a broad education and perhaps doing a double major. Many students have only a vague or very narrow understanding of what a career in physics might entail and such intensive one-on-one advising helps them solidify their thinking and see the advantages of studying physics. For some students this first meeting is the last time they will seek advice except in their senior year when they are job hunting or looking into graduate or professional schools. Others keep closer contact by dropping in for a "quick question" or by e-mail.

## C.2. Physics Major of the Future? One Flexible Approach

Vijendra K. Agarwal
Moorhead State University, Moorehead, MN 56560

The declining number of physics majors in the nineties has been an issue for discussion for most physics departments. The APS Council resolution (APS News, July 1994) which calls for preparing students for a broad range of careers and urges physics departments to reexamine their programs was taken very seriously by our department at Moorhead State University. Since that time, the department has conducted a survey of area businesses and consulted many industrial and academic professionals in an attempt to respond to the changing realities and expectations of the work place.

Considering limited employment opportunities for traditional physics majors, the department has developed several flexible curriculum options to choose from. These options include physics with business concentration, physics with mass communication focus and 3-2 (physics + engineering) program in cooperation with the Institute of Technology at the University of Minnesota. Our survey shows that the background in business related courses will definitely be a tremendous advantage. Many potential employers have repeatedly told us that they generally look for well grounded and broadly educated individuals with good problem solving, communication, management and cooperative skills. Particularly, small to medium size businesses prefer to hire someone with working knowledge of business/management principles together with science background.

As a department, we have also reexamined our course requirements for physics major i.e. not minimizing it but making it more practical. We have made the following major changes;

a. *Quantum Mechanics* has been moved from the required course listing to being one of the electives. As expected, this issue was discussed considerably and consensus was reached that those students going to Graduate school will be very strongly encouraged or perhaps forced to take this course. However, for other tracks this course was not considered to be a critical requirement. All students in physics are required to take a course on *Modern Physics* and thus get some exposure to quantum mechanical principles.

b. We introduced an *Internship* (up to 4 credits) as one of the electives in physics major. The internship experience provides exposure to many skills that academic experience cannot. In the present environment of difficult job situation, the internship experience provides an edge. It is our expectation that during internship, students will be working on projects that may even fulfill the requirements of a *Senior Project*.

Although, the proposed curriculum innovations are relatively new and not yet fully implemented, our continued dialogue and discussion with professional colleges, both in academia and industrial setting, have been positive. The following are some example comments from company executives in our survey:

- Physics majors with skills in business, chemistry, or other options would have a strong possibility for employment at this company…an employee working here would need to have many skills…could use an intern.
- …very willing to have an intern and would like to work with an area universities so graduates are more prepared for the work force.
- …would need a physics trained student and computer background was very important to the company.
- …most employees do technical sales work…felt that Industrial students were not quite as employable as a physics student. This company is very receptive to working with interns.

It is important to realize that the proposed curriculum choices may not lead to doubling or tripling the number of majors overnight but they hold promise for institution like ours. At a minimum:

1. Proposed options increase the employability of physics majors with added course work in business/management and internship experience.
2. Students not willing or able to go to Graduate school in physics can choose other options without giving up their passion for physics.
3. Development of such programs cultivate the collaborative environment among faculty form diverse disciplines which are long considered to have no overlapping curricular interests.

## C. 3. Preparing Physics majors for secondary-level teaching: The Education Concentration in the Haverford College Physics Program

Lyle D. Roelofs
Haverford College, Haverford, PA 19041

It is easy to document both the strong demand for physics teachers at the secondary level and the rather poor qualifications on average of persons currently in those positions. Many undergraduate physics majors who might otherwise be interested in teaching high school physics, however, do not pursue that career option because the requirements for certification are quite strenuous in many states. We have accordingly developed at Haverford College a *concentration* in education for physics majors which provides experiential preparation for teaching physics but requires fewer courses beyond the standard physics major than does the typical curriculum leading to certification.

The concentration consists of a total of 6 courses: 4 are offered through our Education program and provide a general introduction to education and a final semester summary seminar. The other two are novel courses developed by and offered in our department in which the student learns, by doing, how to teach physics. These courses are typically taken by advanced undergraduate physics majors and involve participation in the instruction of our introductory course for non-majors. One of the two involves the student in teaching laboratory physics--activities include presentation of pre-lab comments, a critique of an existing experiment, and the development and testing of a new experiment. The other course involves the student in the classroom portion of the introductory course. In it he or she attends and critiques class sessions, participates in the development and grading of exams, leads sessions providing individualized assistance in problem solving, leads one class session during the semester, develops a demonstration to use in that class presentation and becomes familiar with the modern literature on physics pedagogy with emphasis on peer instruction and misconceptions.

Although a program leading to certification in secondary education is available at our institution, most of our majors who are interested in teaching have opted for the concentration route described here. The career options for a B.S. physics major afforded by the concentration include proceeding directly to a teaching position in a situation that does not require certification. (Most private schools do not require starting teachers to be certified, and in addition many states--19 as of this writing--have approved so-called *Charter Schools* which operate with public funding, but under charters that relax many of the strict mandates that govern teacher appointment in public education.) Or a student may enter an M.A. program in teaching and obtain both that degree and certification in a little over a year, thus becoming highly qualified--and also highly sought after--for teaching positions in any school setting.

Since 1993 eleven of our graduating majors have gone on to education careers: one obtained certification as an undergraduate here; eight moved directly into teaching positions with just their B.S. in physics, most having taken the Association courses; and two obtained Masters degrees with certification before beginning to teach. A full description of this program including syllabi is available; please write to *lroelofs@haverford.edu*.

## D.1. Parallel Parking an Aircraft Carrier: Re-engineering the Calculus-Based Elementary Physics Sequence at Illinois

David K. Campbell, University of Illinois
Urbana, IL 61801

The talk is a progress reports on our efforts at UIUC to re-engineer entirely our calculus-based elementary physics sequence. The new courses are

Physics 111, a 4-unit course on mechanics;
Physics 112 , a 4-unit course on E and M;
Physics 113, a 2-unit course on fluids and thermal physics; and
Physics 114, a 2-unit course on waves and quantum physics.

I start by describing our overall situation: we educate "in bulk" (about 3500 students per year) and we have "collective ownership" of the courses, i.e., faculty rotate through in about a 3-year cycle, so maintain continuity of any revision is key. I then discuss the 3 key motivations for change--to improve the students' learning experience, to improve the faculty's teaching experience, and to provide flexibility for our "clients" (engineering departments) who want some freedom to tailor the physics sequence they take to their students' perceived needs. Our design goals have been to involve the students more actively, to provide many approaches to learning the material (using methods developed and tested by physics education research), and to enhance the training of TAs. The four components of the courses are (1) labs, based on the "predict,observe, explain" approach; (2) "lectures", which look *deceptively* like ordinary lectures but (crucially) contain 3 active learning segments (ACTs)[1] in each lecture which allow the instructor to assess students' comprehension immediately and respond accordingly; the lectures are "scripted", so they are available on the web (beforehand, except for the ACTs) and are available in hard-copy for purchase by the students; (3) discussion sections, in which the students work in groups on context-rich problems; and (4) homework, which is done on the Web with CyberProf, an intelligent interface that provides feedback and hints on the problems and can grade the problems if desired. Faculty staffing is by a team of 3 professors per course.

I then present some samples of lecture material, including an ACT from Mechanics. A new course--Physics 100--is intended as a means of bringing under-prepared students "up to speed" to cope with the concepts/approaches of college physics. This program works at UIUC because of committed individuals, team players, and administrative support. The talk ends with a summary of lessons we've learned.

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[1] E. Mazur, *Peer Instruction (Prentice Hall, 1997).*

## D.2. How Things Work: a Novel Approach for Teaching Physics to Non-Scientists

Louis Bloomfield, University of Virginia
Charlottesville, VA 22903

*How Things Work* is a course for non-science students that introduces them to physics in the context of everyday objects. *How Things Work* reverses the traditional format of physics courses by starting with whole objects and looking inside them to see what makes them work. Because it concentrates on concepts rather than math, and on familiar objects rather than abstract constructs, *How Things Work* serves both to reduce students' fears of science and to convey to them a substantial understanding of our modern technological world.

At the University of Virginia, *How Things Work* consists of two independent one semester courses. Each course covers about 25 familiar objects, ranging from bicycles to clocks and from microwave ovens to nuclear reactors. In each case, the most important physical concepts are introduced as they're needed to explain how the object works.

In the 6 years that I have taught *How Things Work* at the University of Virginia, most of the more than 4000 students who have participated in the course have found it a useful and enjoyable component of a liberal education. They come to see the understanding of physics as a basic skill that will assist them in innumerable situations throughout their adult lives. On a broader scale, *How Things Work* has precipitated a cultural change at the University of Virginia--physics and the physics department are no longer excluded from the rest of the academic community. Students from every part of the University have come to recognize that they can understand physics and that it does have something valuable to say to them.

The title *How Things Work* is magic--it attracts a larger and more diverse audience of students than I could ever have imagined. But I am not alone in this discovery. Both the title and the associated course concept have been invented and reinvented a number of times at a variety of institutions. What I offer to the academic community are the lessons I have learned from my experiences teaching the course and the course materials that I have developed for it--most notably my textbook *How Things Work: the Physics of Everyday Life* and the Instructor's Manual that complements the textbook.

For more information, see the following web site: http://howthingswork.virginia.edu/course.html

## Innovations in Undergraduate Education - Participant Contributions

1. *How the World Works and Using Science Fiction to Teach Astronomy*
Alfred University
David DeGraff, david@merlin.alfred.edu

2. *Principles of Physical Science (a course for elementary and special education majors)*
Bloomsburg University of Pennsylvania
P.James Moser, mose@bloomu.edu

3. *In Class Practice Problems*
Chattanooga State Technical Community College
Dr. Sam Nally, snalley@cstcc.cc.tn

4. *Innovation: The Constructing Physics Understanding in a Computer-Supported Learning*
Environment Project (CPU Project)
Eckerd College and Erksine College
Dr. Anne Cox (Ekerd), coxaj@acasun.eckered.edu

5. *Assessment Devices Particularly Suited to Influencing Student Understanding and Participation:*
Greenfield Community College
Peter Letson

6. *Just-In-Time Teaching with the World Wide Web: Physics For Scientists and Engineers, Phys 152/251*
Indiana University Purdue University
Dr. Gregor M. Novak, gnovak@iupui.edu

7. *Computational Physics*

Illinois State
Professor Richard F. Martin, Jr., info@entropy.phy.ilstu.edu

8. *Computers in the Upper-Level Physics Curriculum*
Laser Physics in the Undergraduate Curriculum
Lawrence University
Dr. David M. Cook, David.M.Cook@Lawrence.edu

9. *New Junior-Senior Curriculum*
Oregon State University
Kenneth S. Krane, kranek@physics.orst.edu

10. *Introductory Physics: Twenty-First Century ICP/21*
Seminole Community College
Alexander Dickison, acidkison@ipo.seminole.cc.fl.us

11. *Remedial Science Courses for Entering Freshman*
Southeast Missouri State
Dr. Midhael L. Cobb, Chairman, http://www.semo.edu

12. *Introductory Physics Course for Both Majors and Non-Majors*
Swarthmore College
Peter J. Collings, PCOLLIN1@swarthmore.edu

13. *Interactive Video for Introductory Physics*
University of California at Santa Barbara
Mark Sherwin, sherwin@physics.ucsb.edu

14. *Design of Multi-Disciplinary Courses for Non-Science Majors*
University of Chicago
Isaac Abella, David Oxtoby, and Lorna Straus

15. *A Mathematica Based Introductory Physics Lab*
University of Cincinnati
Richard Gass, gass@physunc.phy.uc.edu

16. *A Project Oriented Introductory Physics Laboratory*
University of South Carolina
C. Steven Whisnant, whisnant@sc.edu

17. *Physics 109N Home Page: Galileo and Einstein*
University of Virginia
Michael Fowler, http://www.phys.virginia.edu/classes/109N/home.html

18. *Converting to an Engineering Physics Major*
University of Wisconsin-Platteville
Philip W. Young, youngp@uwplatt.edu

19. *Energy in the Environment - A First Year Seminar*
University of Vermont

Robert Arns and Kevork Spartalian, office@mscurie.physics.uvm.edu

## E.1. Breakout Report: Reward Systems for Faculty

Leaders: Lyle Roelofs, Haverford College
Ken Krane, Oregon State University

Approximately 30 chairpersons participated in this breakout group discussion on the general subject of how institutional rewards/recognition practices can better foster excellence and innovation in teaching. Recommendations we agreed upon are set off from the text in bullet format.

Hiring an individual is the first 'reward' bestowed upon him or her, and is therefore one of the most important elements in the rewards/recognition structure. Most colleges seek to appoint to their faculties persons who have previously demonstrated a serious interest in teaching. Therefore

- Graduate programs should allow interested students significant teaching opportunities beyond the routine TA and should work to change the 'cultural' landscape that tends to discourage such activity at most institutions.

In the interest of truth in advertising and to encourage future candidates for college positions,

- Colleges should be explicit in advertisements about their interest in candidates who can provide evidence of serious interest in teaching.

After an individual is hired his or her senior colleagues usually focus on supporting the new professor in establishing a research presence. Furthermore, structures that encourage the development of the ability to carry out scientific research are in place and extend all the way from graduate school to the first years of an academic appointment. Encouraging good teaching is undertaken less uniformly and systematically. Therefore, we believe that

- Mentoring the development of effective and innovative teaching is just as important and necessary as supporting new appointees' efforts to establish productive research programs.

On the issue of re-appointment and tenure decisions, it was noted that methods for evaluating excellence in teaching are inherently quite different from how one judges research achievement. The latter is usually more readily and reliably judged. Furthermore, structures that encourage the development of the ability to carry out scientific research are in place and extend all the way from graduate school to the first years of an academic appointment. Evaluating and encouraging good teaching is trickier, and less uniformly supported. Nevertheless most of the institutions represented are serious about their efforts in this area. The methods that have been developed for evaluation of teaching success in connection with academic promotions are quite diverse, and the group recommends that

- A suitable equipped group should undertake the task of collecting, compiling and publishing the various procedures used by academic institutions to evaluate teaching effectiveness in connection with tenure decisions and other promotions as these many novel approaches might be useful if more broadly known.

There was also consensus that it is difficult and perhaps even misleading to attempt to numerically weight the importance of teaching and research in tenure decisions. It was our sense that the science faculties are more effective in our institutions when candidates are expected to be successful in both areas. Therefore

- It is appropriate for institutions to expect of their faculty both excellence in teaching and research productivity and that the absence of either is reasonable grounds for denying tenure. Such expectations should, of course, be clearly indicated to candidates at the time of their initial appointment.

To ensure that senior professors continue to bring energy, innovation and effectiveness to their teaching activities most of the institutions represented in the group use some form of mandatory evaluation at intervals ranging from 1 to 5 years. Such evaluations are often the basis for the allocation of both monetary (salary increases) and non-monetary (examples include: beneficial course scheduling, usually within the context of nominally uniform teaching loads; release time for course development; etc.) rewards. This being so it seems worthwhile to state that

- It is appropriate for institutions to review on a regular basis the teaching effectiveness of their senior faculty and to use such reviews as the basis for allocation of both monetary and non-monetary rewards.

## E.2.(a) Breakout Report: Flexible Curricula

Leaders: John Mateja, Department of Energy
George Skadron, Illinois State University

1. The group endorsed flexibility as a means of better serving physics majors' differing interests. We viewed it as a broadening of educational and career options. It is implemented by increasing elective courses and options and lowering the number of required courses.

2. Greater flexibility brings a responsibility for better academic advising to ensure that elective courses or options are chosen in a cohesive manner.

3. We need to survey employers to learn what they are seeking in broadened physics education; The American Institute of Physics could play a large role in this market research.

4. In recognition of the growing importance and success of areas such as biological sciences and complex systems, we need to bring down the walls between disciplines and increase interdisciplinary dialogues.

5. The Worldwide Web should be used to quickly disseminate information on flexible physics curricula.

6. We need to assess the success of flexible curricula by creating a database of B.S. physicists in industry.

## E.2.(b) Breakout Report: Flexible Curricula

Peter Kahn, Stony Brook

Our commentary is responding to two stimuli:

1. Enrollment in physics is declining, while interest in biology is increasing;

2. The number of our majors who go on to graduate school in physics is decreasing.

Responses and Recommendations:

A. Increase the flexibility of graduation requirements for the major so students can graduate in 4 years and also co-major or minor in another field or engineering. This means decreasing the number of required courses for the B.S. Degree for students who do not intend to go to graduate school in physics - and permitting substitutions from departments such as chemistry or engineering in order to help students broaden their education.

B. Introduce topical courses to capture interest.

C. Throw out or delete courses and material which, although important, hinders students from exploring other fields and disciplines.

D. Learn how to use WWW resources to offer information about things done at other schools and incorporate some of this material in local courses.

E. Improve advising through the admissions office rather than the advising center.

F. Develop multiple tracks (see A) to encourage diversity of career goals.

## E.3.(a) Breakout Report: Courses for Non-majors

Leaders: George Spagna, Randolph-Macon College
L. R. Sulak, Boston University

This breakout session addressed the question of "Why physics courses are neither competitive nor attractive to the non-physics major?" (Can't we even find a more positive term than non-physicist?) We explored the experiences of some 50 chairpersons, two-thirds from 4 year colleges and one third from universities with graduate programs. The problems appear to be the same for physics departments from both types of institutions (except the concerns of large class sizes and the use of teaching assistants at the big universities, which we did not address).

The clientele for physics courses dedicated to non-majors can be divided into two classes:

a) Non-science majors, who are generally required to take a science distribution course. For these students, physics is in heaviest competition with biology-based courses, where the subject is familiar fom high school courses, and does not suffer from the stigma attached to the word "physics". Generally we fare best with those students who have had a positive experience in high school physics, but that is a small minority. We also lose out to courses based on geology and astronomy.

b) Pre-professional students, primarily pre-medical and engineering students who are required to take an algebra or calculus-based physics course. Here the students are generally bright, but they resent taking a required-course which they feel (even afterwards) has little relevance to them. Their bad experience in physics leads to a large group of technically-trained people with a negative attitude toward physics.

For the non-science major, the goal of us physicists is to capture this largely untapped audience and to excite them about science in general, and physics in particular. We want to show them what science is good for in real life. This is a major opportunity to turn around the generally negative attitude students have toward taking a physics course. For the pre-professionals, our aim is to inculcate the physicist's approach to critical thinking and problem solving. As a spin-off, we may even convert some of these students into physics majors.

Our breakout group developed a consensus on the following suggestions for physics departments:

1) In addition to the traditional evaluations of teaching at the end of each course, we need to assess the attitude towards physics developed by the students during the course: "Are you more positive and receptive to physics than before taking this course?" "Why or why not?" We need this and other instruments to measure the success of our public relations effort with these students, the future leaders of their fields and voters on science funding.

2) To attract non-science students who would not normally opt for a course carrying the "p" word, we must invent non-threatening course titles and themes, e. g. the "How Things Work" course at the University of Virginia. We can get the goal of "looking at the world and analyzing problems as a physicist" through the back door. Only by developing broad-based conceptual courses with large throughput will we eventually affect public attitudes. It is not "us" vs. "them": We must take what they want to learn, and transform it into what we want them to learn.

3) We should pull students into physics by appealing to their special interests, e.g. music, lasers, cosmology, history of science. It is easy, and natural, to segue from their specific interest into a broader approach to conceptual physics.

4) In class, we should use demonstrations, peer participation, students involvement in experiments, and other means to engage the student's minds. For newly developed courses, before all the bugs are worked out, we should put the showman teachers on display.

5) We should involve those students who are not mathematically inclined by written and oral participation, e.g. term papers and essay questions, to allow them to demonstrate their mastery of and competence in the physics material.

6) We should use labs as a natural opportunity to give individual attention to students. Further, they provide hands-on experience to a generation largely lacking it.

## E.3 (b) Breakout Report: Courses for Non-Majors

Leaders: Albert Menard, Saginaw Valley State University
Robert Reynolds, Reed College

*1. Summary as presented verbally:*

Participants in the discussion quickly recognized that widely differing characteristics of the institutions represented meant that the problem of "courses for non-majors" was actually a range of different problems. We agreed to discuss under the general headings of a) courses for non-physics majors and b) courses for non-science majors.

a) Non-physics majors

These courses are largely intended for pre-engineering or pre medical (or comparable life science) students. Design of such courses is generally subject to constraints: there is the problem of the nature of secondary school preparation for the physics course (input-imposed constraints) and the expectations of the customer (output-imposed constraints). Both of these are somewhat aggravated by the role of standardized tests -- AP examinations for incoming students and the expectations of exams like the MCAT on students taking our courses. Another problem is the perceived "need to cover" a certain body of material in such a course.

Proposed solutions:

i) press agencies that design tests to reform their tests to reflect recent progress in science education, stressing understanding rather than computational facility.

ii) get better information from clients about their actual needs (probably miss-perceived at present), not neglecting the value of what can be conveyed about problem solving, the nature of science, etc., but in an attempt to focus our efforts better.

iii) design texts to provide needed materials rather than to be absolutely encyclopedic.

b) Non-science majors

These courses are relatively unconstrained and offer opportunities for real creativity. They ought to meet the needs of citizens: to be able to think, solve problems, understand the process of science (model-building, experiment, replication, publication, peer-review, etc.), read and evaluate news, make intelligent judgments. The group believes that physics courses ought to develop (or at least point out) bridges to other fields (biology, chemistry, geology, oceanography, etc.); that we should talk to colleagues in these fields in order to find out how they think we can best do this. We should value the flexibility that is currently available to us in meeting these needs.

*2. Other points that arose and that were not explicitly noted in the verbal report:*

a) Students who take college courses in science while in high school often have a harder time getting college credit for them than they do getting AP credit for high school courses.

b) Some good books exist for life-science physics: Sternheim and Kane's *General Physics* and Cameron and Skofronick's *Physics of the Boyd*" were mentioned.

c) It is more valuable for students to think about the effects of changing parameters than to apply formulas.

d) Pharmacy schools, queried about their objectives for students taking a physics course, tend to reply "For the student to survive your course."

## F.2. *"The Future of Physics: A View from Washington":* What's Happening? Why? How Does it Affect Us? What can we do about it?

Robert Eisenstein, National Science Foundation
4201 Wilson Boulevard, Arlington, VA 22230

There is great excitement in the physical sciences, the public and politicians strongly support science and technology, and the country needs what we do. However, there are budgetary and political realities with which our discipline has to deal, and cohesive action is necessary. The National Defense budget is now only 20% of government outlays, while entitlements of various kinds account for 55% of government outlays. The remaining 25% is roughly equally divided between payment on the national debt and discretionary spending.

Since there is such enormous political pressure to balance the budget, while somehow not cutting anything but the discretionary line, it is essential to make the case strongly and well for support of the sciences as a whole. We must emphasize the huge "value added" that science brings to American life in every sphere from new discovery, to education, to economics, and to defense. This will involve scientists becoming much more involved in the political process than they have been recently-- "all politics is local" -- while also making every effort to discharge our civic and societal responsibilities.

Another major change that has occurred in spending patterns is that now 55% of the research budget at universities is going into the life sciences. The role that Physics plays in this area is much more substantial than people generally realize. The basic message is that there is a LOT of very stiff competition out there for the precious federal research dollar, and it is no way a given that the dollars will continue to flow to physics.

While growth in the NSF budget is expected to be modest, today that is a real triumph. Neal Lane and the Science Board are evidently interested in supporting research areas such as “knowledge and distributed intelligence”, which has to do with computation and information in all of its aspects. Another major area for emphasis is *science education* and a broader participation in science by all Americans. Again, while these topics are outside the traditional areas of research for physicists, we do make tremendous contributions to them. This needs to be stressed and developed further.

Last, we must continually emphasize the exciting and forefront research and education that we do, and be sure that we as scientists are focusing on frontier problems that the general public will -- at least to some extent -- be able to understand the rationale for supporting. In other words, this is an investment in the nation's future which we neglect at our peril. We can do these things, but it will take our serious attention and significant effort.

## G.1. Achieving Ethnic Diversity

James Stith, Ohio State University
Columbus, OH 43210

The background for this talk is over thirty years of working with students at both the graduate and undergraduate levels, Additionally, my discussions with numerous physics and other faculty members about the subject have in large measure shaped my thinking. Those who read my recent Physics Today article will recognize much of what I will have to say.

Departments should work to achieve a diverse student body because it is the right thing to do! It not only strengthens the department/program, but it helps to prepare all students for entry into the work force and society in which they will eventually work.

The institutional and departmental obligation to the student does not end with the admitting process. The following are characteristics of programs which have been successful in recruiting and retaining underrepresented students:

- There was an individual that took ownership of the program.
- The Department had personal contact with students, both before and after they were admitted. The best students were invited to visit the campus.

- Strong and successful attempts were made to build a close knit physics group. Having good students interacting with one another provides a positive influence.
- The departmental faculty was willing to share their experiences and excitement about physics with their students.
- Advisors gave honest advice. Faculty did not "water down" the material.
- Departments established a level playing field. Important information and material was made available to all students.
- An atmosphere existed in which the expectation of both faculty and students was that students could and would succeed.
- Students were treated as part of a family. They were made to feel as if they belonged.
- Financial aid was provided.
- Students were made aware of the opportunities that exist and of the requirements necessary to take advantage of those opportunities
- Transition opportunities to other fields are explicitly discussed
- Faculty and administrators help students shape their vision.
- Graduate school advisement is explicitly given.
- Ideas are borrowed and adapted liberally.

In most of the successful programs, a mentor, who may or may not have been in the department, played a valuable role in the student's progress. These mentors:

- Invest time and resources in the academic and professional development of the protégé
- Accept the protégé as a legitimate student who has potential for academic success
- Communicate with the protégé in an open and honest manner
- Give sound, constructive, and critical review of the protégé's work, free of judgmental bias
- Are advocates for the protégé as progress is made toward completion of the degree.
- Hold the protégé to high standards of academic output.
- Help sponsor and promote the protégé into the profession.

The conventional wisdom is that college students who major in science, mathematics and engineering are those who became interested early in life. Yet, we find that nearly as many students decided to major in SME after their sophomore year in college as stayed with the decision to major in SME made as high school sophomores . Maybe it is time for us to rethink the conventional wisdom and work to provide for a smooth transition between majors.

## G.2. Mentoring the Whole Life of a Physics Major: From Recruiting and Introductory Classes to Research and Careers

Neal B. Abraham
Bryn Mawr College, Bryn Mawr PA 19010

Often when we think of "mentoring", we have in mind the one-on-one relationships that are formed with thesis students with whom we have extended conversations and interactions for a summer, an academic year, or the multiplicity of years during the pursuit of a graduate-level degree.

Or we may think of mentoring as the service we provide to senior majors as we counsel them about careers. I would like to describe a complex mixture of mentoring activities, from early in the recruiting of new students through strategies in introductory and intermediate courses, to internships and research experiences and career counseling. What works? The answer is that many things work, and no one thing works for every student. To make anything work for a new student, the successful old programs and interventions often need to be repackaged, personalized, and invigorated with energy and compassion. And to make the task more interactive and more difficult, what works one year often does not work the next. Successful programs are often forgotten by students from one year to the next and they may not be as successful the next time because the local needs and context have changed. You must listen carefully, act thoughtfully, assume nothing, and bring a renewed personal and friendly touch over and over again.

It is well documented that a disproportionate share of students from under-represented groups earning bachelors degrees in physics (and the sciences more generally) come from colleges and universities whose student populations have substantial numbers of students from those groups. Additional facts include the following: predominantly undergraduate colleges and universities have a disproportionate number of physics majors; research and career internships help both to attract and retain students; informal and formal peer teaching nurture confidence; teamwork and human-scale faculty members can have an immense impact on the social rewards of doing physics; there is a synergistic effect of student peers. That these institutions carry out their tasks with a certain missionary zeal, cannot be denied. But I think that a close look at these successful programs offers insight that can benefit all students in many different kinds of institutions. The programs leading to this success can be accomplished on many other campuses and they turn out to be equally valuable for women, men and members of under-represented groups.

The New York Times in November 1995 and Physics Today in August 1996 touted the numerical strength of the physics major program at Bryn Mawr College, a private liberal arts college for women which graduates a total of about 300 students each year. Let me review some of that strength in numbers and diversity: approximately 40% of the undergraduate students take introductory physics in one of four different courses, approximately 30% of the graduates take their degrees in mathematics or science, and, over the last two decades, the number of physics majors has grown steadily, although fitfully. Currently (and for at least the next two years) five percent of the graduates take (will take) their degrees in physics, practically 100 times the national average for women as a percentage of the women in their graduating class. In 1995 Bryn Mawr's ten women physics majors were surpassed only by Harvard's 15 and Rutgers' 11. That some form of this success has been going on for quite some time is evident from other statistics: already twenty years ago, more than 5% of the women listed in the APS directory had received one of their physics degrees from Bryn Mawr, Bryn Mawr physics graduates are on the faculty of departments at Michigan, MIT, Connecticut, and Rice; they work at Goddard and JPL; and they include the Director of the Physics Program at NIST in Gaithersburg. In 1993, four of the twenty women elected Fellows of APS were Bryn Mawr graduates. In recent years about 1-2% of the 150 women earning Ph.D.s in physics each year earned A.B. degrees from Bryn Mawr and a similar number earned Ph.D.s in related fields: astronomy, astrophysics, materials science, chemical physics, physical chemistry, engineering, and medical physics among others. But these represent barely a third of our majors, and others are successfully pursuing medicine, law, high school and secondary teaching, and work in science museums, industries, and research labs. In 1997 we graduated 15 physics majors (five of them double majoring in other departments: mathematics (3), biology (1), philosophy (1)). We have an additional 15 senior physics majors enrolled for the fall of 1997.

What do I mean by whole life mentoring? The answer is that we must seek to intervene and provide counsel, comment and insight at each stage of a student's thinking about physics. We start our mentoring activities even before studens enroll. We discuss opportunities with staff at the Admissions Office, we provide posters about our programs in the corridors most frequented by prospective students and parents as the follow tours, and we provide scripts to the tour guides themselves. We prepare handouts for prospective students with descriptions of our programs and graduates and with answers to frequently asked questions. We emphasize flexibility, opportunity and lots of advice throughout the program. Once students enroll at Bryn Mawr, we work closely with each student who gives even a hint of wanting to take more physics. We give advice about placement, make special arrangements to accomodate those with unusual preparation in math or physics or both, entice some to take more physics earlier, entice some who were wavering to take some physics, and we continue to meet with students who have questions or who seem puzzled about the future. We work hard to give personalized encouragement to students who are doing well, and to specifically encourage them to take more physics.

We try to provide a richly diverse set of educational, learning and teaching experiences (both those in formal class and lab settings and those in informal consultations with faculty and fellow students. By what we grade and require, we try to affirm a variety of learning styles and a variety of different kinds off demonstrations of mastery. We also encourage and arrange internships and research experiences throughout the four years of the undergraduate experience), counsel students to consider a wide variety of careers, and, at each level, demand excellence and insist on involvement. We encourage all undecided students to consider taking our departmental placement exam which serves as a basis for assessment and counseling about starting points in the curriculum. We also make early contact with those qualifying for advanced placement by external AP exams or International Baccalaureate degrees, since some of those students are daunted by the maturity that is expected in sophomore courses. One early message in mentoring the whole life of a student is that you must stay in contact in order to provide advice and support.

We have tried various options for our introductory courses. They are most successful when they have a minimum of pre-requisites, when they have a combination of applications and an emphasis on conceptual understanding, and when students are encouraged to talk, write, discuss, and think about physics in more than chalkboard, engineering homework and textbook-based kind of ways. Demonstrations can often be distracting and inconclusive; we find that mixing demonstration apparatus with laboratory equipment gives students a sense of continuity and participation that improves their mastery. Our labs are relatively conventional, but we often try to see that they have a twist. Ours are rarely "prove the theory by experiment", or "fit the theory to the experiment", since some aspect of the idealized problem is tampered with to give anomalous experimental results. The student teams and the teaching assistants and instructors then search for explanations, reducing a larger class to only two or three investigators. We also try in lab to have different subgroups of students doing different things; This is hard on instructors but challenging for the students. We use demonstration apparatus in the laboratories for conceptual labs -- “Take this material, figure out some interesting phenomena and questions and write us an essay about the issue and the evidence.” We also find it is important to build student confidence, especially in the introductory courses: some students may focus on the 10% wrong answers and not internalize the endorsement by a 90% correct score on an exam. Sometimes we give midterms back in person to take the chance to offer a few comments or words of encouragement. Sometimes we approach students in lab or in the corridors to assure them that they are doing well enough to major. In short, we find that the best way to expand the pool of majors beyond the "hard core", is to provide advice and encouragement.

We also share within the department the tasks of helping students to plan their curricular choices. Our major program is probably more enticing because there is lots of room for choice among the curricular offerings and because substitution of other advanced math and science classes is permitted. We frequently find ourselves helping individual students to rearrange their futures (curricular plans, at least), and I suggest that it is not enough to offer this service once a year, or even once a semester, because students benefit most from this kind of advice in those crisis moments of indecision or choice. We also encourage students to gain perspective on their "home" education by taking summer research internships off campus at other colleges or universities or in industrial or government labs. In undergraduate colleges this can be a sacrifice, since to prepare a student one often invests one summer in the intensive supervision of the apprenticeship and then hopes for the second summer as the more productive "payback" time. We find that students gain much more maturity and confidence from working with those who had not taught them more elementary subjects and from returning to campus with summarized accomplishments which their local mentors had not seen pass through the foibles stages. This choice is thus not one that every department or every faculty member may wish to emulate, particularly at smaller and predominantly undergraduate institutions, but we find the efforts we make to find placements for juniors, some seniors, many sophomores and a few freshmen has paid off in better, stronger, and more confident majors.

We also have a vigorous program of research opportunities during the academic year and summers for students. Here again the twists of mentoring can lead to additional success. We have a program sponsored by college funds to "apprentice" students as faculty members, so that they can see the whole life of a faculty member. In this program we are encouraged to help the students participate in the design and uncertain phases of a research project, in the assessment and ordering of equipment and apparatus from the instrument shops, and in regular reassessment of the goals and accomplishments. In some contexts it is argued that it is important to make a research project "successful" or "conclusive". Instead we have found that it is equally valuable for students to have some insight into the doubts, despair, and moments of indecision that are natural parts of our professional lives. We have a similar program for teaching apprentices and involve those students in preparing and assessing assignments, examinations and class presentations.

Another way to mentor is through providing advice in a variety of media: printed handbooks, posters, and Web sites are among the ways we try to make information available. Our brochures, poster boards and Web site range over such topics as careers, preparing for teaching, preparing for the GRE, where recent graduates are working, and how to plan for different flexible futures. We update them often and discuss them with students over pizza and soda in the evenings. We also frequently mix with students to discuss time and stress management, to review our curriculum, and to have meals with our colloquium speakers. Our evening (dinner time) speaker program held in the dining center has been the most successful way to draw students and has give them the opportunity of dinner with other physicists. We have found that our own contacts, alumnae, and speakers list from the Committee on the Status of Women in Physics (CSWP) give us a nearly inexhaustible supply of women with diverse careers, talents, topics and stories. One way to mentor your majors is to recruit others to share in the mentoring!

We rely less on the infrequent visits by outside women than on the daily support networks that develop among students within the department: programs and facilities range from a "majors' room" with computers and lockers, key access to kitchenette and computers and classrooms, desks in research labs for students doing research, mailboxes for messages, homework solutions in the conference rooms as well as in the more distant library, student-run evening physics clinic for answering of questions. With a little luck and lots of synergy, our majors have come to think of the physics department as the place where they can and will find each other for teamwork or companionship, for problem solving or relaxation. They mentor each other as much, indeed even more sometimes, than we mentor them.

In conclusion (for this shorter story) I suggest that mentoring has three primary tasks: giving honest advice, instilling confidence, and leaving room for growth. Among the best ways to do this are:

- share secrets of successful teaching and learning strategies
- validate student mastery and career choices
- ensure a personal and socially supportive atmosphere
- be aware of the fragility of success

Perceptions are reality: what you meant or thought you'd done are irrelevant if they contradict the stories students have in their own minds. Classic chilly climate features of low expectations, mindless assignments, or sexist (racist) attitudes or remarks can destroy careful plans and good intentions -- each of us must be forever on guard to encourage and support. One misstep may destroy the atmosphere for a generation (2-4 years) of students. Become accustomed in your conversation and examples to use pronouns and career choices that reflect your students' interests: "The scientist..., she"; "he engineer who describes her work,...". Avoid describing parents and siblings as part of "the non-science community".

And finally, for good and effective mentoring, keep asking, keep trying, and keep listening. (A more complete and detailed version of thoughts about mentoring activities at Bryn Mawr is in preparation for posting on our Web site and perhaps for submission to the Forum for Education Newsletter.)

## G.3. Retaining Women and Minorities in Physics: Directions and Strategies for Change

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Important directions for physics departments thinking about including women and increasing diversity are as follows:

(1) increasing the number of women and minorities doing physics,

(2) cultivating gender equity awareness and practice, and

(3) becoming involved in the rethinking of science that is occurring in the humanities and social sciences -- through historical, philosophical, and cultural analyses of science with respect to gender and race/ethnicity.

While the focus here is mainly on women, many points apply to minorities as well. Key resource materials for each of these three directions are available on the Web through the University of Rochester, Department of Physics and Astronomy site, Program for Women in Science and Engineering at this URL: http.//www.pas.rochester.edu/yigal/wise-intro.html

*1. Increasing the number of women and minorities doing physics.*

Although this is usually considered the final goal, it is also a direction departments can take: finding ways to increase the presence and participation of women and minorities in the department. The main strategy has been to establish intervention programs specifically targeting underrepresented groups, for instance, girls and young women. We can also include here efforts by departments to admit women and minorities as graduate students and hire them as post-docs and faculty, as well as outreach activities (e.g., having faculty visit schools).

The concepts operating in such programs and efforts are as follows:

(1) exposure (e.g., of young women) to the world of physics (ex: pre-college programs for girls, or research experience for first-year college women), and of department members to higher numbers of women; and

(2) personal contact between young women and persons working in the physics world (contact in the form of regular program-based meetings, mentoring, including peer mentoring).

Among issues that departments must consider is the need for dedicated personnel -- at least 0.5 FTE (full-time equivalent), but preferably at least 1.0 FTE -- to write the grant proposals, manage the program(s) from beginning to end, and ensure that the experience is positive for all parties. This work takes time, ongoing effort, and support from chairs and other department members. While it is not necessary for many persons affiliated with a department to actually run the programs, active support -- and protection from institutional down-sizing -- is essential for persons who run programs or otherwise engage in professional activities aimed at achieving diversity.

It is perhaps important to state that, however effective programs for girls and women are (and they are effective), they are probably not the wave of the future, given the erosion of affirmative action policies at the federal and state levels. Thus, there is a need for other directions and strategies if we wish to make progress toward a more diverse physics community. At the same time, the principles of exposure and personal contact continue to apply to all types of efforts that serve those entering the world of science.

*2. Cultivating gender equity awareness and practice in departments.*

In this case, the main strategy has been workshops targeting faculty and/or teaching assistants to raise awareness of issues affecting the participation of women and minorities. Some departments have invited external reviewers to assess the "climate" for women; another method is departmental self-assessment, involving a thoughtful review of pertinent data and information at, for instance, a departmental meeting or retreat.

The operating concept here is creating time and space for faculty to think, individually and collectively, about the structures, policies, and practices that organize life in the department -- in terms of inclusiveness and fairness. The goal is individual and departmental self-change, through awareness of the issues which women and minorities face as they enter the world of physics.

Departments must consider several issues in the implementation of workshops: the need for effective facilitation (possibly an external, skilled facilitator); the amount of time faculty will commit to an "extra" activity like this; voluntary vs. mandatory participation; the sensitivity of the issues, and the potential to generate resentment rather than constructive awareness.

Perhaps the overriding issue is that workshops fall outside those activities which faculty consider part of their job as academics -- workshops and the issues they deal with are "extra" and therefore marginal, less legitimate, less important. To get around this obstacle, one needs to design activities to fit within existing, familiar, and accepted academic and departmental structures, such as seminars and colloquia, graduate student orientation, instructor training (if this exists in the department), mentoring programs, and department meetings.

*3. Becoming involved in the rethinking of science that is occurring in the humanities and social sciences -- through historical, philosophical, and cultural analyses of science with respect to gender and race/ethnicity.*

This might be considered an intellectual approach to increasing the number of women and minorities or cultivating gender equity awareness. Rather than pushing the issues of women's and minorities' participation to the margins of institutional life, this approach addresses those issues within the curriculum, the heart of what goes on in colleges and universities.

The main strategy is to create interdisciplinary courses, working in collaboration with departments of women's studies, African-American studies, history, cultural studies, religious studies, and philosophy. Such collaborations might also yield interdisciplinary seminars, seminar series, or conferences, or invited speakers at regular departmental colloquia.

The concept behind such courses (and related efforts) is to gain a deeper understanding, not only of who participates in science (and who doesn't) and why, but also of science itself. Out of such understanding can eventually emerge the kind of cultural change needed in the world of physics to make the inclusion of women and minorities "normal." Without a deeper understanding of the issues, however, physics departments may continue -- in a sense unconsciously -- to resist the entry of women and minorities, and lasting change may be impossible.

It is also important to see activities in this area as part of physics -- or at least adjacent to physics, much the way one might combine business, teaching, policy, or other disciplines with science, either as an area of interdisciplinary study or as a career path. For students, such courses open up new vistas in their thinking and create new study and career options, drawing some toward "traditional" science and some away from traditional science toward the humanities. If and when physics faculty get involved, the insight they gain is likely to feed back into the design of intervention programs and reflection on gender equitable practices in their department, including the content and pedagogy of physics courses.

What this is not: Social studies of science are not about, for example, Great Women of Science, the triumph of science over superstition, or other familiar themes. What this is (or can be): Such studies generate questions that shift our perspective on the issues of women and minorities in science.

Historical studies raise questions like: What were the social conditions and beliefs that excluded most women from science, as science became a profession? What were scientific (or pre-scientific) activities in which women did engage, albeit without recognition as scientists? And, what did the new profession of science (in the 17th and 18th century) have to say about sex and gender difference?

One finds, for example in the work of Londa Schiebinger, that class, country, and connections (to scientific men) were important determinants in whether or not a woman took part in scientific activity. One finds that as science moved away from the courts, the salons, and the guilds, and as it moved into the universities and academies, women were increasingly excluded. One finds that women (and a few men) did protest and argue for women's access to learning -- they did not take their exclusion as a given. And one finds that the profession of science, and the actual knowledge produced by science, colluded in the exclusion of women, using the new methods of observation, measurement, and experiment to justify women's unequal status. While the history of the relationship of people of color to Western science is not identical to that of European and American women, a similar theme is found of using of science to explain and justify their subjugation, "Other"-ness, and exclusion.

Culturally oriented studies look at such questions as: What are distinguishing features of the professional culture of science? Where does this culture come from? How might it contribute to the absence of women in science? David Noble has made an extended argument that Western science is rooted in Christian clerical culture and is essentially the outcome of a thousand years of efforts to create a "world without women." Evelynn Fox Keller has addressed the questions: Is science "masculine"? Why does it seem so? What does this mean? Her work speaks to the effects of removing women from science, of polarizing ideas into "masculine" and "feminine" categories, and of overvaluing so-called masculine qualities of knowledge, at the expense of so-called feminine qualities.

Recognizing that science failed to be "objective" in relation to gender, philosophical studies have asked: Is science objective at all? What is objectivity? What determines the degree of objectivity in science? Helen Longino, for example, has argued that objectivity is a social process, not an individual one. Objectivity depends upon the capacity of a community to hear and respond to criticism from all qualified participants; and science benefits by cultivating diversity -- of backgrounds and ways of thinking -- among its participants. Donna Haraway points out that any observation, whether by human or technological "eyes", is necessarily embodied and situated (in space, time, and culture); science cannot give us a total or an exact representation of nature, only a collection of embodied, situated interpretations of nature -- each of which may have particular uses. Sandra Harding, among others, has asked: What have been, and what could be, the uses of science -- political, economical, or otherwise?

What, and who, is science good for? Scholarship in this area has moved beyond critique to formulating the basis for an inclusive, diverse science.

In conclusion, adding women to physics clearly is momentous -- particularly if one contemplates that it may be a reversal of a thousand-year project to realize a "world without women." It is important to recognize that including women in science comes with the "shoe horn" of the women's movement and feminism. "Feminism" here refers not only to promoting the status of women; it also means bringing to the foreground parts of human history, culture, and knowledge that have traditionally been in the background -- ignored, devalued, or suppressed. Cultivating gender equity and educating ourselves in women's studies and other social/cultural studies of science are feminist practices.

Such studies, such practices enable us to go from talking only about more women becoming physicists to also talking about physics becoming more feminist. Physics departments need to go in both of these directions. Both will generate vitality in undergraduate science education and sustain physics into the future. And both are necessary if we are to bring about positive change in the culture of physics and realize a truly diverse physics community.

## G.4. Undergraduate Independent Research at Princeton

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Stewart Smith described the implementation in Physics of Princeton’s universal requirement that each student write a junior indpendent paper and a senior research paper. Faculty members take this responsibility very seriously, and students cite the importance of this experience in their undergraduate education. Evidence was presented that the requirement can work effectively with students of quite different ability levels and interests. Some of the projects typically lead to publication.

## H.4. Breakout Report: Recruitment & Retention of Women & Minorities

Leaders: Anthony Johnson, New Jersey Institute of Technology
Priscilla Auchincloss, University of Rochester

*Barriers to women and minorities:*

- Our profession generates what is often perceived as a chilly climate.

- Subtle socio-cultural dynamics in introductory classes often inhibit under-represented groups and are not noticed by instructors.

- Instructors reveal low expectations of some students by how long they wait when posing questions.

- Difficult career prospects discourage potential entrants.

- Students don't know the ropes.

- Large classes can generate fear.

- Foreign teaching assistants (T.A.s) often treat men and women differently due to cultural factors.

*Why is it different in other fields (e.g.: medicine, law, other sciences)?*

- Individuals make a difference
- Historical & cultural factors can strongly influence a field's receptiveness.

*What can we do? Some suggestions:*

- "Physics as a Profession" - a 1 credit course (Arizona State University)
  - Starting a chapter of the Society for Physics Students and providing separate spaces for students can be useful.
  - Attracting minority and women faculty can improve a department's climate.
  - Improve the mentoring provided by faculty members. Student progress should be carefully tracked.
  - Utilize peer-mentoring, which is especially helpful when difficulties arise.
  - Implement better training of T.A.s: utilize role playing and video methods, teach about body language and behavior, cultural differences and language modes, and gender differences.
  - Take advantage of the expertise of minority and women faculty members at other institutions.

## H.5(a) Breakout Report: Student Assessment and Measurement of Learning

Leaders: Cynthia Galovich, University of Northern Colorado
Stephen D. Ellis, University of Washington

It is necessary to distinguish between *program assessment* and *student assessment*.

*I. Program Assessment*

A. For program review (for peace of mind & for administration) use external groups. (The American Association of Physics Teachers can help with this).

B. For help in redesigning one part of a program, one can use outside consultants from other institutions.

C. Accreditation is a form of program assessment that can help the status of a department in the administration's view and help place graduates. Accreditation/certification is a big success story in chemistry.

*II. Student Assessment*

A. There is a need for a central, public database for assessment information. It should be made available to chairs (can AAPT do this?). This includes:

i. Standardized tests on overall physics knowledge;

ii. Subject-based concept tests (mechanics, thermodynamics, etc.);

iii. Literature on methods of assessments.

iv. Names and locations of experts in assessment (not necessarily in physics)

B. Important Components

i. Retention - tracking performance of students through the physics program. One also needs data on students as they enter college/university (ACT/SAT).

ii. Attitude - All agree that it is important, but how do we assess it? Inquiry - has the course helped the student to see/appreciate the utility of physics?

iii. What do we do for the majority of students (non-physicists). Are attitudes and concepts more important? We should use the NSF Guidelines on expectations for scientific literacy.

C. Since standardized testing and statistics present problems for smaller departments, they should assess more frequently. Students buy into assessment because they see how it affects their education. Value added is seen by both faculty and students. Attitude and concept understanding can be readily assessed several times in one course. The more data the better - and at least initially, a variety of tools/approaches should be used. This way, you discover what works best for your faculty and students.

## H.5 (b) Breakout Report: Student Assessment and Measurement of Learning

Leaders: Robert Hilborn, Amherst College
Robert Chang, University of South Florida

Graduate Record Exams - The main question is "Are GRE scores a good indicator or assessment of a student's potential for graduate study in Physics?" While we all use GRE scores to screen applicants, especially those from foreign countries, we should look for evidence of independent research effort. Larry Kirkpatrick of Montana State University said future GREs will have fewer questions and more emphasis on conceptual understanding. Suggestions for improvement of the test format are welcome. AAPT should look into national tests (including MCAT) and evaluate how well the Physics portion is conducted. Some small departments reported difficulties in providing adequate coverage of material (e.g. nuclear physics) for the GRE exam.

Assessment - Are students learning and professors achieving the actual goals of their courses? Outcome-based assessment and "authentic assessment" will be the answer to this question. There are some concerns about having more tests and more data for analysis that may not be conclusive. Some departments have comprehensive exams for graduating seniors and evaluation of effectiveness of learning Physics in laboratory. Test instruments for General Physics, though incomplete, are available from AAPT. The University of Maryland and Arizona State University have conducted an attitude assessment which compares the students' level of interest in physics before and after taking the course. Embedded assessments such as those demonstrated in Session B of this meeting are considered to be very effective means of measuring learning.

## H.6 (a) Breakout Report: Undergraduate Research: Making it Better

Leaders: Peter Collings, Swarthmore College
Howard Brooks, De Pauw University

Undergraduate research experience is important. As such, it should be supported at the same level as other courses and laboratories. Successful research projects require a committed faculty sponsor. The sponsor must be given allowance for using undergraduates in research projects, in all promotion and tenure decisions. The sponsor should be given support materials such as the AIP publication, *How to Involve Undergraduates in Research*, and materials from the Council on Undergraduate Research. Safety issues cannot be ignored.

The match between student and project is critical. We cannot ignore student interests, ultimate career intentions (individual or team), and research styles (i.e. on-campus, at another campus, in industry). Each project should ideally be summarized in both oral and written reports. Intermediate progress reports can ensure a good final report.

Graduate schools should interpret student research as being indicative of graduate school interest. The goal is for the student to experience the process of doing physics.

Many schools encourage off-campus summer research. We would recommend a national clearinghouse for summer opportunities to insure that no slot goes unfilled and that the maximum number of students have the opportunity.

To summarize, students may not be as productive as experienced researchers, but bright undergraduates can do a lot.

## H.6 (b) Breakout Report: Undergraduate Research: Making it Better

Leader: Warren Hein, AAPT
Tony Pitucco, Pima College

All of those present at this breakout discussion felt that research participation at the undergraduate level is essential. Several participants discussed how they get students involved as freshmen using small independent study investigations, either with or without credit. Bill Bickle from the University of Arizona shared two pages of projects that he had worked on with first-year students. These require very low overhead in terms of faculty time and often times involve students from other majors (music, art, drama) who have a physics question that can evolve into a small project. Concern was expressed about the likely cutback in funds for Department of Energy (DOE) education programs. These benefit both the participating laboratories (by getting researchers involved in the education process and by the direct contributions of the participants to the research) and the students and faculty members that participate in the program. Funds are available to support undergraduate research through Research Experiences for Undergraduates (REU), private companies and foundations, Society of Physics Students grants, and internal support from departments. The Council on Undergraduate Research is a good resource for sources of private funds. It was pointed out that faculty members with NSF grants can frequently get NSF supplemental grants to involve students through the REU program; not enough faculty take advantage of this grant opportunity.

It is important that oral and written presentations be a required part of all undergraduate research experiences. This might be a talk at a state, regional or national meeting, a paper in the Journal of Undergraduate Research in Physics, or a paper in a well-respected refereed journal. The department can use these presentations and papers as recruitment tools to encourage students to major in physics.

Concern was expressed about how faculty members' participation in undergraduate research is viewed for promotion and tenure considerations, especially at larger universities. Reward systems may need to be changed to encourage improvements in undergraduate education.