The goal of this program is to receive Pennsylvania Teacher Certification for Physics grades 7-12 as well as general science, as well as a Bachelor of Science in Education.
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Welcome!

As the Physics Education Coordinator, I would like to welcome you to our program. It is a challenging yet rewarding program of study. The Commonwealth of Pennsylvania requires that a certified Physics teacher has similar background knowledge as a content major – therefore, upon graduation, you should consider yourself a Physicist whose area of expertise is teaching.

Physics teachers are among the most sought-after in the field of education. You serve your students as well as the community by passing on the fundamental knowledge of science. Your will usher your students into the world of physics.

Do you interact well with others? It’s an important quality for successful educators. A BS-Ed in Physics is designed for those who want to become a role model by inspiring secondary students to grasp the expansive power of physics.

BS in Education–Physics

- Develop the skills needed to earn a teaching certification for physics in Pennsylvania junior high and high schools.
- Acquire practical experience in methods courses and student teaching.
- Gain a strong foundation in math and physics.
- Fulfill science requirements as well as core curriculum for the College of Education.
- Your course of study culminates in student teaching, your first true experience as a science teacher.

What our students say

Learning How to Pass Knowledge to Others

“Everybody’s there to learn how to help others learn. It’s an interesting situation, where everybody is so focused on knowledge itself.”

“My final semester of student teaching at Homer Center was imperative to my growth as a future teacher.

This handbook is just a start of your journey; it contains some information that might help you get started. There are other guidebooks for pre-service teacher, such as the pre-clinical guide books as well as the Student Teaching Handbook. They can be found on the college of education web site:

http://www.iup.edu/teachereducation/forms/default.aspx

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George is the machinest for the College of NSM.
You should get to know the secretary REALLY WELL!
Advisement and Registration Student Advisement

*What is an advisor?*

Your advisor is an IUP faculty member who can assist you in planning your schedule, understanding your program, and providing information and counsel during your undergraduate years with IUP.

*Who is my advisor?*

Dr. Stanley Sobolewski - 344A Weyandt Hall, (724) 357-4590, Stanley.Sobolewski@iup.edu

*When should I meet with my advisor?*

Students are required to meet with their advisors each semester prior to registration in order to discuss progress in the program and to address individual questions. Advisors usually add additional office hours prior to the beginning of the registration period so that students will receive pertinent and timely registration information. Consult with your advisor to determine how they prefer to schedule appointments.

*What should I do when I meet with my advisor at registration time?*

The following suggestions will be helpful as you work each semester with your advisor.

- Maintain a folder with your own course sequence sheet and checklist and copies of ALL important documents. Bring the folder with you, so you can double-check requirements and recommendations for courses.
- Before your advising meeting, write down questions you may have. Be sure to ask questions!
- All students are expected to bring a current copy of the IUP transcript (printed from MyIUP is fine) to their advisement meeting and have completed a proposed schedule for the upcoming semester.
- Complete your advisement form to the best of your ability prior to seeing your advisor. Your advisor will review and sign your advisement form and give you one of the copies. Keep your form in your personal folder throughout your studies.
- With your advisor, complete two graduation checklists. Keep one checklist in your personal folder and your advisor will maintain one in the office. In addition to the advisement meetings, general informational meetings may occur each semester. Students are expected to attend and are responsible for the material presented in the meetings. The PSE Departmental website (http://www.iup.edu/pse) and the Special Education and Clinical Services website (Special Education and Clinical Services - Indiana University of Pennsylvania), are sources of information and students should refer to the websites when they have questions. Students are expected to use IUP’s e-mail system and to check e-mail accounts regularly. IUP professors frequently correspond with students via e-mail.

*What are my responsibilities in terms of understanding my program?*

All students are expected to take personal responsibility for reading about, understanding, and following their required academic program. While the advisor can provide assistance and guidance, you, as the student, must be sure that you are fully aware of the expectations of your department and your program. Although your advisors are partners in your academic success, it is ultimately your
responsibility to understand your program and to make certain that you are taking the correct courses in the correct sequence.

IUP is dedicated to providing students with excellent advisement. Students are expected to take responsibility for being fully informed every step of the way about their programs. Through this partnership, students are ensured to have a positive and successful advisement experience.

**How do I take a class from another higher education institution and apply it to my major?**

Consult the “Credit Evaluator” on-line for information ([Pre-approved Coursework - Registrar - IUP](www.iup.edu)), then visit Transfer Admissions (117 Sutton) to complete the required paperwork.

**What is an override?**

An **override** is a procedure where students may be assisted in gaining entry into certain classes. Overrides will not be issued to students for courses for which they are not qualified, nor will they be issued under normal circumstances for course sections that are full/closed. See the Department Secretary for information regarding specific questions/circumstances.

**How can I take more than 17.5 credits?**

Visit the NSM office or web site to secure a form permitting you to take 18 or more credits. Approval will be granted depending on number of credits and your GPA (detailed on the form itself).

**How can I earn a minor?**

Academic minors are listed by IUP College online and in the Undergraduate Catalog. Visit the department or departmental web site that offers the minor or minors of interest for additional information.

**Registration Process**

All students must register at IUP every semester. It is important that you register on time so that book orders, financial aid, and classroom assignments are correct. Please follow these detailed instructions in order to complete this important process correctly:

- Log onto [www.iup.edu/myiup](http://www.iup.edu/myiup) and print your transcript from IUP.
- Use your IUP transcript to complete/update your IUP Program of Study Checklist.
- Please register PROMPTLY so that you will get the courses and schedule that you need.
- Before you can register with IUP, you will need to schedule an appointment with your advisor.
- At your advisement session:
  - You will receive your Personal Identification Number (PIN) for IUP’s online registration system, as well as your specific registration date. Please note that your PIN changes each semester.
  - You will also receive registration instructions with the IUP courses required for the upcoming semester. Each course will have a Course Reference Number (CRN) that is used to register on IUP’s online system.

- Go to [www.iup.edu/myiup](http://www.iup.edu/myiup) to register for your IUP courses. Use your PIN when prompted and use your registration instructions to enter the CRN for each course. (You do not have to search for the course; instead, go to “Add classes.”)
- Please be sure to print your registration when you are done, so that you have a record of your IUP schedule. (If you have a “hold” on your IUP account, you will be unable to access your transcript and/or register for classes. Having a “hold” often means that your account is not paid. Check with IUP Student Accounts at (724) 357-2207 to clear this matter up as quickly as possible.)
IUP Three Step Process for Teacher Education

**Step 1: Requirements for Admission to IUP Teacher Education Program**
*These requirements must be completed before the beginning of the junior year:*
- A minimum of a 3.0 cumulative GPA after 48 earned credits
- Successful completion of Pre-service Academic Performance Assessment* (PAPA) exam and a minimum score established by the PDE.
- Completion of the following courses with a grade of “C” or higher: ENGL 101, ENGL 121, EDSP 102, EDEX 103, and 6 credits in Mathematics MATH 151 and MATH 152
  - Act 24, Act 34, Act 114, and Act 151 Clearances
  - Proof of professional liability insurance
  - Completion of speech, hearing, and TB tests
  - Satisfactorily completed philosophy statement
  - Electronic portfolio
  - Advisor’s recommendation and signature

*Alternative PAPA requirements: Students who successfully achieved the following scores prior to enrolling at IUP are exempt from taking the PAPA.
  1. A score of no less than 1550 on the Scholastic Achievement Test (SAT) including scores of no less than 500 on the Critical Reading, Writing and Mathematics Subtests
  2. A composite score of 23 on the American College Test Plus Writing accompanied by a combined English/Writing score of 22 and a Math score of 21.

**Step 2: Requirements for Admission to Student Teaching**
*These requirements must be completed before the beginning of the senior year:*
- Successful completion of Step 1
- Maintenance of a 3.0 GPA
- Successful completion of PECT exams (The score for each PAPA and PECT test must be less than ten years old AND at or above the current PDE established score at the time a candidate applies for Pennsylvania Teacher Certification)
  - Act 24, Act 34, Act 114, and Act 151 Clearances
  - Proof of professional liability insurance
  - Electronic portfolio
  - Advisor’s recommendation and signature

**Step 3: Requirements for Graduation and Pennsylvania Teacher Certification**
*These requirements must be completed in order to graduate and receive your teacher certification:*
- Successful completion of Step 2
- Successful completion of Student Teaching
- Maintenance of 3.0 cumulative GPA
- Completion of the Electronic Portfolio
- Completed application for graduation
- Completed application for Pennsylvania Teacher Certification
- Advisor’s recommendation and signature
- IUP Teacher Certification Officer’s recommendation and signature
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The Top Ten FAQs about IUP Libraries

Q1: When is Stapleton Library open?

A1: Regular hours of operation are:
   Monday–Thursday: 7:45 a.m.–12:45 a.m. Friday: 7:45 a.m.–7:00 p.m. Saturday: 11:00 a.m.–
   5:00 p.m. Sunday: 1:00 p.m.–12:45 a.m.
   For library hours during breaks and summer sessions, click on the “Exceptions to Regular
   Library Hours” link at the bottom of the IUP Libraries homepage (http://www.iup.edu/library).

Q2: How do I search for a book in Stapleton Library?

A2: Books, online government documents, and media may be located using IUP Libraries’
   online catalog (PILOT). PILOT is accessible through the IUP Libraries homepage
   (http://www.iup.edu/library) on or off campus without your I-card by clicking on the “Books &
   More” link.

Q3: How do I locate a book or a video in Stapleton Library? A3: Write down or text (using the
   “text me this call number” feature) the call number of the item you’d like to locate. Call numbers…
   • that begin with REF (designating a reference book) are located on the first floor.
   • that begin with the letters A – L are located on the second floor.
   • that begin with the letters M – Z are located on the third floor.
   • that begin with the word OVERSIZE are located on the third floor.
   • that begin with VCV (VHS tapes) or DVD designate videos. Videos are housed at the Media
   Circulation Desk on the first floor.

   Also,
   • Children’s books will display their library location as “Children’s Collection” in PILOT. The
     Children’s Collection is located on the second floor across the breezeway in the Stabley section of the
     library. Children’s books either have Dewey (designating a nonfiction book) or LC (designating a
     fiction book) call numbers.
   • Books that are part of the popular reading collection, or “Schafer Collection,” are located on
     the first floor by the elevators.

Q4: How long can I check out a book or video?

A4: Undergraduate students may check out a book for 30 days and renew it twice (30 days each
   time). Videos may be checked out for two days with no renewal. 17

Q5: Where do I go to access digital library resources?

A5: IUP Libraries’ databases may be accessed through the library’s homepage
   (http://www.iup.edu/library). Click on the “Articles & More” link to search for a database by title,
   keyword, or subject.

Q6: How do I access IUP Libraries’ databases from off-campus?

A6: When you click on the database title, you will be taken to the KLN PASS page. In the block
   on the left, where it asks for library barcode or ID, enter the 16-digit number on your I-card and then
   your last name. The system will check you against our patron database and, if you are a valid user,
   pass you through to the database you want. If you are unable to authenticate, please contact the
   Circulation Desk at (724) 357-2340.
Q7: How do I access databases that are designated “ON-CAMPUS ONLY or VPN” from off-campus?

A7: To access “on-campus only” databases from off-campus, you must set up a virtual private network (VPN) on your home computer. Instructions for setting up the VPN can be found under the “Distance Education” link on the IUP Libraries homepage (http://www.iup.edu/library).

Q8: Can I print in the library?

A8: Yes. However, you have to have money on your I-card in order to use the printers. A machine for putting money on your I-card can be found on the ground floor of the library. If you forget your I-card, there is an I-card at the Circulation Desk (located on the first floor) that you can use. You will need to give the worker at the desk your driver's license to hold until you return the card, and you will need to pay for your copies. Currently, copies are 4 cents per page for black-and-white and 25 cents per page for color.

Q9: Where do I go to find materials that my professor has put on reserve?

A9: Print reserve materials are housed at the Circulation Desk. You will need to provide your professor’s last name. Digital reserve materials may be accessed through the IUP Libraries homepage (http://www.iup.edu/library) by clicking on the “Electronic Reserve” link. Your E-Reserve password is the first three letters of your professor’s last name, the course prefix, and the course number (no spaces).

Q10: Where do I go if I have questions about my research?

A10: Stop at the Reference Desk on the first floor of Stapleton Library. Reference librarians are trained to assist you in finding appropriate resources. They can often help you find what you need in less time. If you need more specialized service, contact the Education Librarian, Dr. Kelly Heider (kheider@iup.edu), to set up a consultation.
Challenges in Teaching and Learning Introductory Physics

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INTRODUCTION

In a volume intended to celebrate Bill Little's many contributions to fundamental and applied research in physics, an article about teaching the most elementary aspects of physics may seem somewhat out of place. But a substantial part of Bill's well-deserved reputation is based on his excellence as a teacher, especially for the introductory courses for engineers and biological science majors. This article is offered in homage to his tradition of excellence in education.

During his distinguished career, Bill has served as a mentor to a great number of graduate teaching assistants. In large part, I owe what success I have had as a physics educator to what I learned from Bill during my own teaching assistant days at Stanford. My goal in this article is to attempt, however feebly, to carry on his tradition.

In particular, I will discuss some aspects of the introductory physics course that will be of interest (and perhaps surprising) to new college physics teachers and new teaching assistants. I hope that this article will also be of use to the "old hands" who, like me, discover something new about teaching every time they go into a classroom or talk with a student.

The challenges involved in teaching an introductory course in physics are legion, so my goal in this brief article is not to be comprehensive --- merely provocative! References 1 and 2 include a variety of other tips and suggestions for physics faculty and teaching assistants.

WHY INTRODUCTORY PHYSICS EDUCATION IS IMPORTANT

The relative importance of teaching in the physics enterprise has increased dramatically in recent years. As federal funding for research decreases, the golden era in which newly-minted physics Ph. D.s were guaranteed at least a postdoctoral research position is becoming an ever more distant memory. A larger fraction of the available academic positions emphasize teaching, especially at four-year and two-year colleges. Even at research universities, teaching is now playing a larger role in promotions and tenure decisions. In this brave new world, a physics graduate
student who aspires to an academic career dare not neglect the teaching side of her or his
graduate training.

While teaching physics at all postsecondary levels --- beginning undergraduate, advanced undergraduate, and graduate --- is important, the greatest importance attaches to the introductory courses taken by students in their first two years of college. For the budding physics major, these courses are the ones in which the student gets his or her first taste of the subject and decides whether or not to pursue the bachelor's degree in physics. The basic understanding achieved in these courses is the foundation for all subsequent study in physics.

The real importance of the introductory courses, however, lies in those students who are not physics majors. Indeed, the vast majority of students in introductory courses are likely to be engineers (in a calculus-based course), premedical students (in an algebra-based course), or humanities majors (in a "conceptual physics" course). These students constitute the educated electorate of the future, and their introductory physics courses are the only chance that we physicists have to plead our case with them.

The dominant public perception of physics is that it is tedious, abstract, and fundamentally irrelevant; the challenge in an introductory course is to convince the audience that physics is rewarding, fun, useful, and most of all a worthwhile endeavor. If we fail in this, and the public perception of physics does not change, there is little chance that future physics research will be funded at anything more than a token level. In this sense, introductory physics teaching is the foundation not only of a physics education, but of the physics enterprise as a whole. We neglect the teaching of these courses at our own grave peril.

WHY JOHNNY CAN'T ANALYZE CIRCUITS

College students begin most of their courses in a state of nearly perfect tabula rasa. Before they take their first course in world history, in economics, or in psychology, they know little or nothing about those subjects. The instructor can then help the students to implant fresh knowledge upon the palimpsests of their minds.

The situation in an introductory physics course is quite different. Although they would be shocked to hear you say it, students arrive in their first physics course with a set of physical theories that they have tested and refined over years of repeated experimentation. How can this be? The reason is that students have spent some eighteen years exploring mechanical phenomena by walking, running, throwing baseballs, catching footballs, and riding in accelerating vehicles. They have also some more limited experience with electrical phenomena, garnered from using electric circuits in

the home, and about the behavior of light, lenses, and mirrors. Based on their observations, students have pieced together a set of "common sense" ideas about how the physical universe works.
Unfortunately, research carried out by physicists has shown these "common sense" ideas are in the main incompatible with correct physics. Worse still, these erroneous ideas are robust and difficult to dislodge from students' minds, in large measure because these ideas are not addressed by conventional physics instruction.

As an example, Fig. 1 illustrates some representative "common sense" ideas about electric circuits. In part (a) of the figure, a battery is connected to two identical light bulbs $A$ and $B$ in series. In part (b), the battery is connected to a single bulb $C$ which is identical to bulbs $A$ and $B$. McDermott and Shaffer [3] asked students in introductory physics courses to compare the brightnesses of bulbs $A$ and $B$ in circuit (a) and to compare these with the brightness of bulb $C$ in circuit (b).

![Figure 1](image.png)

**Figure 1.** (a) A battery connected to two identical light bulbs $A$ and $B$ in series. (b) The battery is now connected to a single bulb $C$ which is identical to bulbs $A$ and $B$. When asked to compare the brightnesses of the bulbs in these circuits, only an embarrassingly small number of students gave the correct answer even after instruction in circuit theory.

The results of this investigation were incredibly disappointing. The correct answer, that bulbs $A$ and $B$ in circuit (a) are equally bright and that bulb $C$ in circuit (b) is brighter still, was given by only about 10% of the students in algebra-based courses and by only about 15% of the students in calculus-based courses.

The most remarkable result of McDermott's and Shaffer's study is that the types of student errors made on this question are unrelated to, and unaffected by, conventional instruction. One common student error is the belief that in circuit (a), bulb $A$ will be brighter than bulb $B$ because bulb $A$ "uses up the current first." Another common error is that the brightness of each bulb will be the same in either circuit because the battery provides a constant current in all cases. Neither of these incorrect ideas are learned from an introductory course, but neither are they discredited in a standard introductory course. Indeed, McDermott and Shaffer found that student performance on this question was nearly independent of whether the question was posed before or after instruction on electric circuits. Similarly disquieting results have been found regarding "common sense" ideas in mechanics [4] [5] [6] and in optics [7].
Investigations of this sort show that it is not enough to merely teach students the right way to think about physics. Rather, the challenges to the instructor are to identify possible student misconceptions, to confront these misconceptions head-on, and to help students to unlearn these misconceptions at the same time that they are learning correct physics. Failure to do this will invariably leave students with their erroneous "common sense" ideas intact.

In order to rise to these challenges, an essential tool is an introductory physics textbook that addresses "common sense" ideas explicitly. Sadly, most contemporary textbooks are severely deficient in this respect. But some very recent textbooks make extensive use of research into student misconceptions [8] [9], and these should be given consideration by instructors who are serious about helping students overcome their "common sense" ideas about physics.

"I UNDERSTAND THE CONCEPTS, I JUST CAN'T DO THE PROBLEMS"

Every physics instructor has heard this complaint from students at one time or another. All too often, however, what the student really means is the converse:

"I can do (some of) the problems, I just don't understand the concepts."

Students can usually handle problems that are akin to the worked examples in their textbook, especially if there are "special equations" that they can use. Problems that require using fundamental concepts, along the lines of how we might expect a physicist to think, are another matter altogether.

The proof of this statement is the difference between student performance on "standard" physics problems that require computation and calculation and their performance on purely conceptual, qualitative problems. As an example, McDermott and Shaffer [3] found that even students who performed well on standard numerical problems in circuit analysis, and even students with near-perfect scores on such problems, performed poorly on the conceptual question depicted in Fig. 1.

Part of the difficulty that students have with conceptual questions stems from the kind of problems that students are most often assigned. Instructors commonly assign homework and exam problems that involve computation or calculation, in the belief that these are "real" physics problems. A corollary to this belief is the assumption that a student's ability to successfully solve such problems is evidence of complete understanding. Alas, research shows that such is not the case. One example is an investigation of student understanding of the Newtonian concept of force carried out by Hestenes, Wells, and Swackhamer. [6] By comparing student performance on a set of conceptual questions posed both before and after a first course on mechanics, they found that conventional instruction (including the assignment of conventional homework problems) produces only marginal gains in conceptual understanding.
If we truly want students to learn about the ideas of physics, we must require them to use these ideas in their homework and then hold them accountable for these ideas in examinations. Most introductory textbooks include a wealth of conceptual questions, and questions of this sort these should be assigned regularly. My own students regularly comment that they find conceptual questions to be much more difficult than the "ordinary" problems; such comments convince me that conceptual questions are very useful tools for teaching and learning physics.

**WHAT DOES THAT EQUATION MEAN?**

A related issue is the question of how students deal with formal, mathematical expressions of physical concepts. Two examples are Newton's second law and the work-energy theorem:

1. \[ \sum \vec{F} = m \vec{a} , \]  
2. \[ N_{\text{net}} = \Delta K = \frac{1}{2} m v_{\text{final}}^2 - \frac{1}{2} m v_{\text{initial}}^2 . \]

It is very common for students to interpret Eq. (1) to mean that the product of a body's mass and its acceleration is itself a force. In other words, they fail to realize that a mathematical equality between two quantities does not imply that the two quantities are conceptually distinct. As a result, they do not appreciate that acceleration is the consequence of the presence of a net force. Thus

students frequently make reference to such chimera as "the force due to acceleration" or "the force due to momentum."

A similar confusion arises concerning the work-energy theorem, Eq. (2). When students are asked to explain what kinetic energy means, the most common response is that it is "one-half the mass times the speed squared." By fixating on the mathematical definition, they fail to grasp the essence of the work-energy theorem: that the kinetic energy of a particle is equal to the total work that was done to accelerate it from rest to its present speed, and equal to the total work that the particle can do in the process of being brought to rest.

This tendency to focus on a mathematical definition rather than physical meaning was shown convincingly by Lawson and McDermott. They presented students with a simple question concerning the work-energy theorem. As depicted in Fig. 2, an object of mass \( m \) and another object of mass \( 2m \) are initially at rest on a frictionless horizontal surface. The same constant force of magnitude \( F \) is then applied to each object. The question to be answered is "Which object crosses the finish line with greater kinetic energy?"
Using the work-energy theorem, and keeping in mind the physical meaning of kinetic energy, it can easily be seen that each object has the same kinetic energy upon reaching the finish line. Yet in interviews with 28 students taken from two classes at the University of Washington, an honors section of calculus-based physics and a regular section of algebra-based physics, Lawson and McDermott found that only a few honors students were able to supply the correct answer and the correct reasoning without coaching. While most of the remaining honors students were able to eventually achieve success with guidance from the interviewer, almost none of the students from the algebra-based course were able to do so. No less disappointing results were obtained with a written version of the question presented to a regular section of calculus-based physics. I have had similar experiences with my own students: Their performance on conventional homework-type problems shows that they can compute quantities such as work and kinetic energy, but their performance on conceptual questions shows that they have much more difficulty explaining or interpreting their results.

This example shows again that emphasis on numerical problem-solving can obscure major conceptual deficiencies in students. It underscores the importance of requiring students to apply the fundamental concepts of physics in a variety of different situations, as well as requiring them to explain the logic that they use in solving physics problems of all kinds.

RETHINKING THE LECTURE AND DISCUSSION SECTION

A point that I have stated repeatedly in this article is that conventional physics instruction tends to be ineffective in helping students to develop a real understanding of physics. How, then, should the nature of physics instruction be changed? A number of different approaches have been suggested and explored; I will summarize the approaches that I believe to be the most promising.

The Misuses of the Lecture

The lecture is one of the most ancient of teaching methods. In the teaching of physics, it is typically used to demonstrate physical phenomena, to present derivations; and to show examples of
how to solve problems. The first of these uses of the lecture is an important one, and is often neglected by instructors who feel compelled to "cover more material" or who regard the demonstrations as a distraction. My own experience is that good lecture demonstrations are absolutely indispensable as tools for helping students to relate physical concepts to the real world. Good lecture demonstrations also have the strength of being memorable. I have had students come to me a decade after taking one of my classes and tell me how they still remember a certain demonstration and the physics that they learned from it. (By contrast, I have yet to have a former student tell me how vividly they remember my derivation of the thin-lens formula.) The title "Lecture Demonstrator" is still in use at certain British universities to denote a science lecturer; the title alone speaks volumes about the importance of lecture demonstrations.

By contrast, the use of lecture time to present derivations is typically ineffective. A derivation presented on the blackboard is less useful to the student than the same derivation presented in the textbook, where it can be traced through repeatedly at the student's leisure. My suspicion is that instructors tend to present derivations in lecture because they doubt that their students read the book. While this is indeed a valid concern, it would seem that using the lecture to reiterate the contents of the book is ultimately counterproductive; it merely helps to ensure that the students won't read the book.

Far and away, however, the least effective use of lecture time is for presenting the solutions to physics problems. The essential difficulty here is that physics problem-solving is a skill that has to be learned by repeated practice. In learning a skill, it can be useful to first watch an expert exercise that skill, but that is by no means the most important part of the learning process. If it were, the millions who watch professional sports would themselves naturally develop into top-notch players; avid movie-goers would inexorably turn into accomplished actors (who really want to direct); and the poor souls who watch televised court proceedings would slowly but surely mutate into highly paid defense attorneys. Of course, none of these evolutions really take place. In the same way, students who watch their instructor (an expert problem-solver) work out a solution on the board may be impressed by the instructor's prowess, but they will augment their own problem-solving skills only marginally. The disappointing problem-solving performance of students who have had such conventional instruction, referred to earlier, is testimony to this.

A Lecture Model with "Active Learning"

Numerous instructors, myself included, have found that lectures become more useful when students are forced to become active participants in the lecture. [11] In my own classes, I speak briefly about each new topic (proceeding under the assumption that students have read the required material from the textbook before class), and do a lecture demonstration or two as appropriate. I then give the students an exercise to work out. They then spend several minutes working out this exercise, which is chosen to be specific to the topic at hand: it may involve tasks such as drawing free-body diagrams, writing down (but not necessarily solving) the key equations for a group of related but distinct situations, or making graphs of different types of motion. While this is going on, I roam around the classroom inspecting the students' work. I then instruct the students to confer with their neighbor to compare their responses and to resolve any discrepancies. Remarkably, this works very well even in a large lecture hall; the sound level from the discussions among 300 students can be quite impressive! Finally, I discuss with the students the correct way to tackle the exercise, being careful to point out common errors to the students. I typically do two or three sequences of instructor description --- student work --- instructor discussion during a typical lecture.
This technique has several merits. First, the students have something constructive to do during the lecture; it is a sure-fire cure for the torpor that grips students midway through a conventional lecture. Second, students are forced to discuss physics with their peers and to defend their ideas. Third, students get immediate feedback as to whether or not they understand a concept that has been presented in class, and any points of confusion can be corrected at an early stage in the students' apprehension of the concept. Last, but by no means least, the instructor can learn a great deal about her or his students' understanding of the material. This last point was brought home to me vividly during a lecture when I asked students to draw the free-body diagram for a car rounding a banked curve; many of the diagrams I saw while walking around the lecture hall included a number of creative and wholly imaginary forces that I had never dreamed existed!

When conducting the lecture in this way, it is best if the students have a printed sheet with the exercise on it. These can be time-consuming to develop and to prepare in printed form, however. I have relied heavily on Alan Van Heuvelen's ALPS Kit (an acronym for Active Learning Problem Sheets), and Randy Knight's Student Workbook for Physics: A Contemporary Perspective, which are workbooks containing several hundred exercises and activities expressly designed for student use during lecture. [12] Students purchase these inexpensive workbooks at the campus bookstore, and are required to bring them to lecture; happily, I find that almost all of them do so religiously.

Some will no doubt complain that this technique of "active learning" forces the lecturer to cover less material. It is indeed true that the lecturer talks about less material with this approach; the challenge to the lecturer is to choose between the material that is worthy of discussion during the lecture and the easier material that the students can learn adequately on their own from the textbook. Thus this technique does not require that any material be deleted from the course syllabus.

Employing "active learning" in the lecture keeps students engaged in the lecture. More importantly, it yields substantially better student performance on exams than does conventional instruction. [11] [12]

**Discussion Sections, Teaching Problem-Solving, and "Cooperative Learning"**

Most introductory physics courses have both a lecture component and a discussion section (or "recitation section") component. The discussion section, typically led by a teaching assistant (TA), is intended principally to be a forum in which students gain insight into problem-solving technique by observing the discussion leader, by practicing solving problems, and by discussions with other students.

Unfortunately, physics discussion sections very often fail to live up to this intent. Too many students come to discussion sections with the intent that they will get their weekly homework "done for them" by the TA. As a result, despite the earnest efforts of hard-working and talented TAs, it is difficult to cajole students into actually doing problem-solving work in a discussion section. Furthermore, it is next to impossible to initiate and sustain any real student discussion within the unstructured format of a typical discussion section. The upshot is that few students are able to move beyond the "formulaic" approach to problem-solving, which consists of hunting through the textbook for a likely-looking equation or set of equations into which they can plug the values stated in the problem. This sad state of affairs is especially frustrating for TAs who, after working diligently with a group of students for an entire term, must grade those students' disappointing work on exams.
A very promising effort to rectify these shortcomings of the discussion section has been described by Heller, Keith, Anderson, and Hollabaugh. [13] [14] They reorganized the discussion sections in two rather different physics courses, the first quarter of a large algebra-based introductory course at the University of Minnesota and a sophomore modern physics course with a dozen students at Normandale Community College. In both courses, students were taught a general problem-solving strategy based on the methods used by expert problem-solvers, and were required to write up their problem solutions in a way that explicitly reflects the use of that strategy. (In addition to shaping the students' approach to problem-solving, this technique helps to clarify for the grader what conceptual ideas the students are using.) To discourage "formulaic" problem-solving, students were assigned so-called "context-rich" problems. Such problems do not always explicitly identify the unknown variable, may include extraneous information, and may require reasonable assumptions (e.g., the acceleration is constant) or estimation (e.g., the mass of a typical cat). In other words, they are less like standard textbook problems and more like the problems encountered by real scientists and engineers. The following is an example of such a "context-rich" problem, taken from Ref. 14:

While visiting a friend in San Francisco, you decide to drive around the city. You turn a corner and find yourself going up a steep hill. Suddenly a small boy runs out on the street chasing a ball. You slam on the brakes and skid to a stop, leaving a skid mark 50 ft long on the street. The boy calmly walks away, but a policeman watching from the sidewalk comes over and gives you a ticket for speeding. You are still shaking from the experience when he points out that the speed limit on this street is 25 mph.

After you recover your wits, you examine the situation more closely. You determine that the street makes an angle of 20° with the horizontal and that the coefficient of static friction between your tires and the street is 0.80. You also find that the coefficient of kinetic friction between your tires and the street is 0.60. Your car's information book tells you that the mass of your car is 1570 kg. You weigh 130 lb, and a witness tells you that the boy had a weight of about 60 lbs and took 3.0 s to cross the 15-ft wide street. Will you fight the ticket in court?

Such "context-rich" problems are of the kind that we would like our students to be able to solve, but which are usually thought too difficult and challenging for students to solve on their own. Remarkably, students in both of the test groups described in Refs. 13 and 14 were able to solve such problems when each discussion section was organized into cooperative groups of three students. The students in each group were required to work together to produce a group solution to the assigned problem, using the problem-solving strategy that they had been taught. All students in the group received the same grade for their group assignment. The students in each group were assigned the roles of Manager (who keeps the group on task and manages the sequence of steps), Skeptic (who helps the group to avoid overly quick agreement and asks questions like "Are there other possibilities?"), and Checker/Recorder (who checks for consensus among the group and who writes up and hands in the group solution). These roles were rotated among the students each week. The use of such definite roles, and the challenging nature of the assigned "context-rich" problems, kept the students from simply working independently.
To reinforce the use of the problem-solving strategy and of the skills used in the cooperative groups, each course exam included a "context-rich" problem that had to be solved by the students in their cooperative group during the discussion section. (More conventional individual exams were given during lecture.)

Heller et al. found that over two quarters of using these methods, the problem-solving technique of students of all ability levels improved. [13] It may not be surprising that this proved to be the case for students in the lowest third and middle third of the class. The structured problem-solving strategy and the requirement to discuss ideas with other students seems well-suited to helping students whose understanding of problem-solving was initially only fair or poor. What is remarkable is that participation in cooperative groups also helped the best students in the class to improve their problem-solving skills, and that these students improved at about the same rate as the students in the lowest and middle thirds. For example, the percentage of students in the lowest third of the class whose individual solutions followed a logical mathematical progression improved from 20% to 50% over two quarters; this percentage for students in the upper third improved from 60% to 90%. Furthermore, this improvement of all students was found in both group problem-solving and individual problem-solving.

The use of cooperative groups and "context-rich" problems can have a very beneficial effect on student problem-solving skills. We have just begun to implement these innovations in the introductory calculus-based physics course at UC Santa Barbara, and the preliminary results look encouraging. This method is not a panacea, however; Heller at al. found that their innovations did not have much beneficial effect on students' understanding of the conceptual aspects of physics. [13] This suggests that these aspects are best addressed in the lecture using the "active learning" technique described previously.

CONCLUSION

Teaching and learning introductory physics are both challenging tasks. While traditional methods have led to frequently disappointing results, I have tried to show that there is hope. As instructors, we should heed the lessons about our students' thought processes learned from research into "common sense" ideas about physics and into students' difficulty with formal mathematical reasoning. We must see to it that students truly learn how to use the concepts of physics, in order that they may learn how to think like a scientist or engineer. And we should be willing to consider new forms and new approaches for the time-honored lecture and discussion section. Whatever gains we can make in improving student understanding and appreciation of physics cannot help but improve the public perception of physics as a useful, interesting, and above all comprehensible human activity.

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12. A. Van Heuvelen, Overview, Case Study Physics, *Am. J. Phys.* 59, 898 (1991); R. D. Knight, *Student Workbook for Physics: A Contemporary Perspective* (Addison-Wesley, Reading, MA, 1998). For information on how to obtain the ALPS Kit, contact Professor Alan Van Heuvelen, Department of Physics, Ohio State University, Columbus OH 43210-1106. [First appearance in article]
