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Introducing a Preparatory Physics course

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Abstract

Since many incoming science/engineering majors here at Texas A&M University-Kingsville are inadequately prepared for the required introductory physics courses, we introduced a “Preparatory Physics” course in which we teach not only basic physics, but also fundamental skills necessary for success in science. We present here the scope, characteristics, and techniques used in this course, and report some initial successes in preparing students for the physics courses to follow.

Introduction

Many science/engineering majors arrive unprepared for the trig-based or calculus-based introductory physics sequence (IPS) required for their degree programs. At Texas A&M University-Kingsville (TAMUK), we observe DFQ rates (percentage of students receiving grades of D, F, or dropping the course) as high as 50% in the IPS. Similar results have been reported at other institutions (Selen, 2001; Saul and Beichner, 2001; Churukian 2002; Slavin 2008; Freeman, Haak & Wenderoth 2011). Several explanations are offered: declining standards in elementary/secondary science education (Selen 2001; Churukian 2002), the deleterious effects of “teaching to the test” on scientific reasoning (Gill 1999, Menken 2006), “credentialism” (Slavin 2008), grade inflation at the high school level (Slavin 2008), weakness in mathematical skills (Meltzer 2002).

Some institutions address this situation by offering a preliminary course prior to the IPS, focusing on the basic skills necessary for learning physics, including mastering the terminology of physics, learning to read a physics text profitably, understanding how physical quantities relate to each other, and conceptual and quantitative problem solving. Several institutions (City College of San Francisco, Chabot College, Ohio Wesleyan University, St. Cloud State University, University of Alabama at Birmingham (UAB), University of California-Davis (UC-Davis) and others) have introduced such a course under the name Preparatory Physics (PP).

We introduced a PP course at TAMUK in the Spring semester of 2010. The present author had taught the PP course at UAB 1998-2001, but the TAMUK course had to be tailored to issues unique to this region. Most students taking IPS are engineering majors, to some extent reflecting ethnicity and culture. First, Mexican culture, common to a majority of our students, holds the engineering profession in high regard: to be addressed as “Ingeniero” is a title of respect. Second, a TAMUK student is often the “first college student in the family,” and thus may be unaware of the requirements of an engineering degree. Third, the problem of “teaching to the test” is particularly pervasive at the middle/secondary school level in this region. Fourth, a high proportion of TAMUK students are economically underprivileged. The consequences of this confluence of conditions are enormous, and are discussed below as four specific student deficits in additional to the more general weaknesses shown by students attempting to learn physics. These factors also make TAMUK engineering students more susceptible to what Slavin (2008) calls “credentialism:” the pursuit of a degree solely as the credential for a specific job, with little appreciation of course content.

We structure this report as follows. First, we discuss four serious deficits consistently observed among physics students. Second, we present the structure, method and content of our PP course, as it was developed to meet these specific deficits. Third, we present preliminary data showing that students who took PP did perform better in IPS. Finally, we discuss avenues further improvement of this course.

Specific Deficiencies Observed in Beginning Physics Students

Poor performance in IPS stems not only from weak physics (or mathematics) backgrounds, but also from undeveloped reading, writing and thinking skills. While TAMUK requires remedial algebra and reading/writing, success in physics requires competences not addressed therein. In this section, we examine four serious deficiencies: a near-absence of training in logic and critical thinking; a lack of physical intuition, even when applied to familiar experiences; habituated ineffective learning strategies, and confusion arising from the British system of measurement.

Critical thinking.

Many students have no training in logic, and will present--and readily accept--the fallacies of the inverse, the converse, equivocation, etc., without question and are surprised when their conclusions are graded as incorrect. Although superficially familiar with the relation between cause and effect, they accept the fallacy of “post hoc ergo propter hoc” as true, making it difficult to understand the rules of evidence and the scientific method. Incompetence at logic is often behind student difficulty in perceiving the connection between mathematical formulas and physical reality.

Example: Asked for the formula for kinetic energy, students generally state it correctly as equal to one-half of the product of the mass of the object with the square of its speed. Then the student is asked: “You're driving at 30 mph. You speed up to 60 mph. By how many times have you increased the kinetic energy of your car?” Not only beginners, but even students with a semester of IPS will answer “double” and defend this as “common sense”. Although they can calculate squares and square roots, they fail grasp the application to a physical situation.

Physical intuition.

Because many science/engineering students perceive physics as esoteric, unrelated to everyday experience or even to common sense (Hestenes et al 1992), they don't see that their experience with sports, bicycles, automobiles, machinery, amusement parks, and the like, is part of the physical reality that one studies under the name of “physics.” Although mathematics is often cited as the stumbling block for beginning physics students, the deeper issue is the disconnect between mathematical skills and application (Gill 1999), and we have observed students with three semesters of calculus still having difficulty grasping physical concepts and relating them to everyday experience.

Comparable misunderstandings arise in geometric and spatial reasoning: students frequently confuse surface area formulas with volume formulas. “A spherical balloon is inflated to four times its initial diameter. By how many times has its volume increased?” Even experienced students who recite the volume formula correctly will sometimes answer “four” or at best “sixteen,” failing to grasp the connection between the formula and the physical entity.

Ineffective learning strategies.
Previous experience in quantitative science is often limited to “plugging numbers into formulas” without appreciating why the formula works or what practical use it may have. Out-of-class interaction may reinforce misunderstandings, if a stronger student or tutor simply introduces a formula without explaining how it was obtained or why it works. Some students were taught to cross out every word in the statement of a problem except for the numbers and some “key words,” discarding information about the physical situation. With formulas thus divorced from physical reality, students don't see that the procedure used to solve the problem must be connected to the practical significance of the solution.

While interaction among students can promote learning (Beckman 1990, Thornton 1999, Hake 2002, Slavin 2008), interacting profitably is a learned skill and incoming students are generally unprepared to interact with either the instructor or other students. They must learn how to ask productive questions, understand the answers to their questions, ask sound follow-up questions and formulate problems based on given information. While the formal and quantitative nature of physics may not appear as the stuff of lively discussion, physics involves the communication of ideas as much as any other academic discipline.

The British system of measurement.
Students raised in the United States are accustomed to British units of measure being “natural” in all contexts: although the metric system is taught in middle schools, students regard it as “stuff you learn in school,” irrelevant to “real life” where measurements are made in British units. The most serious consequence for the study of physics is that everyday use of the British system treats *mass* and *weight* as synonymous, while they are in fact two entirely different physical quantities. This misunderstanding becomes incorporated into the student's background “knowledge.” Even students who distinguish correctly between mass and weight in the metric system often cannot apply it in their everyday (British) measurements, as they still treat “weight” as the absolute measure of

how much “substance” is present. They may accept that your weight would be different on the moon, but don't see the mass-weight issue as having earthbound relevance.

Does the “pound” (lb) represent mass or force? That these are conflated in everyday speech engenders fundamental misunderstandings of physical reality that render it difficult to master Newtonian mechanics. Furthermore, students do not recognize that the same physical quantities can be represented using different sets of units, and are surprised to learn that automobile power can be expressed in kilowatts, while electric power can be expressed in horsepower. The continued use of the British system in the USA requires that engineering students be competent in both systems.

Structure and content of the Preparatory Physics course

Our PP course prepares students for both trig-based IPS (taken mostly by biomedical science majors) and calculus-based IPS: following the present author's experience at UAB, the TAMUK course does not use calculus. Because the course must not only teach the fundamentals of physics but must also teach the skills, methods and problem solving techniques needed to address the deficiencies described above, the scope and content is restricted to an elementary treatment of the most basic aspects of Newtonian mechanics. The specific goals of this course are as follows. A student who successfully completes this course will: learn the techniques (including note taking) for read a physics text profitably; be able to distinguish between the “everyday” and the “physics” meanings of words such as force, work, energy, power, etc; interpret equations and formulas in light of both their underlying logic and their connection to physical reality; bring all these skills to bear on solving the problem at hand.

These goals entail confronting counterproductive habits, particularly that of approaching problems by asking, “Which formula do I use?” Overcoming such habits requires experience and practice: students must learn to recognize that everyday experiences can be described quantitatively and in the vocabulary of physics. Thus we emphasize the connection between the formal vocabulary of physics and its quantitative expression, and the familiar experiences (work, sports, amusement parks, etc.) that are the stuff of physics. The student learns to describe this situation in the formal terminology of physics. If it involves a human body in motion, they must not only describe the situation mathematically, but also describe what the motion feels like to the person experiencing it. Students are also taught to “Read the equations and formulas in words, not just in symbols,” preferably aloud. Assembling all of the above, they analyze a physics problem, identify the fundamental physical laws involved, relate the problem to everyday experience, identify the appropriate mathematical techniques necessary to solve the problem, and must also understand and appreciate the significance of the results. Moving beyond this stage, they learn to formulate a new problem in the style of a textbook problem, and are informed that a similar problem will appear on the next exam. Only then should the problem be discussed in terms of the applied mathematics involved.

What does the left side of the equation actually mean? The right side? What does the equal sign indicate as to how they relate to each other? (Students often misuse the equal sign to indicate implication, or attempt to equate quantities with different dimensions.)

Using this question as a starting point, Newton's Second Law is presented in terms of causality: the left side of the equation (the sum of external forces acting upon the object) is the *cause* of a change in the state of motion; the right side (mass times acceleration) is the *effect*--the quantity representing the change in motion of the entity in response to this cause. This introduces the subsequent discussion of the meaning of the "equal" sign in Newton's Second Law.

Conservation of momentum is introduced with a classic illustration: "You're lying in your dormitory bed and the door is slightly ajar. You want to close it, but you're too lazy to get up and walk over to it, so you decide to throw something at the door to close it. Two objects of the same mass are available: one is a ball that will bounce off the door, the other a lump of clay that will stick to the door. Both objects are thrown with the same velocity. Which will close the door more effectively?" The students must attempt to visualize the effect, before any formulas are introduced. This provides a striking example of graphical vector analysis, and shows that an apparently counterintuitive effect can be presented from a perspective that clarifies its meaning.

Instead of a separate laboratory session, students engage in preparing and executing "hands-on" in-class demonstrations. They draw vector diagrams on the blackboard and solve problems graphically in class, both individually and in groups. They participate in identifying problems of a kind that they will likely confront in engineering practice, describing those problems in mathematical terms, and finding solutions for those problems. Projects are also assigned: students may work singly, in pairs or triads, may choose any project that will reinforce the course content, and are encouraged to investigate the physics of something familiar to them from work, sports or hobbies. They present their work to the class, and are expected to demonstrate an understanding appropriate for a student about to enroll in IPS. Other students are expected to respond with comments and questions. Exams are open-book and open-note, consisting of problems. In addition to finding the correct solution, the student is expected to explain each step taken and comment on the significance of the result. Final course grade is determined by class participation, problem-solving skill as demonstrated on homework assignments and exams, and the project.

Preliminary results

Because PP was introduced to prepare students for IPS, it must be evaluated by the students' subsequent performance therein. We gave a basic physics skills test at the beginning of the semester to all students enrolled in IPS, and weak performers were recommended to transfer into PP. The final IPS grades of students who first took PP are compared to those of students who remained in IPS despite the recommendation to transfer to PP. We have student performance data from seven semesters of PP beginning in Spring 2010, six semesters of students who took IPS subsequent to completing PP beginning in Fall 2010, and five semesters of students who first enrolled in IPS, transferred to PP, then subsequently took IPS. As of Spring 2013, 99 students had enrolled in PP, 59 completed it with a grade of "C" or better, and 25 of those students subsequently completed IPS with a combined grade point average (GPA) of 2.52. PP was recommended to 138 IPS-enrolled students; only eight transferred into PP, and of the others, 26 eventually dropped IPS, and the 112 who were graded had a combined GPA of 1.36 (59% DFQ rate). Thus, students who successfully completed PP performed significantly better in the subsequent IPS than underprepared students without PP.

Discussion

A survey of PP at other institutions and the present author's UAB experience show that while some student difficulties are ubiquitous, there are large regional variations in the methods and quality of science education in middle and high schools. Consequently, the PP course must be regionally tailored, and many of our adaptations reflect concerns specific to South Texas. Some weaknesses have been observed in nearly all but the best students; others are associated with, or exacerbated by, regional issues. We have confronted both of these situations with some success, but our PP course still has a disturbing 40% DFQ rate, with some students falling behind early in the course and never catching up. Although some of these students may lack the aptitude for quantitative science, we believe that many more can be helped by a detailed assessment of student weaknesses at the outset, early intervention and some structural changes to the course. Conversations with students reveal that they are well aware of the weakness in their physics background, but are unaware that they lack sound study habits, appropriate reading/writing skills, logical and visualization skills.

In order to become more proactive in identifying and addressing deficits specific to particular students, we identify and address several areas in which the PP course can be improved. First, our perfunctory initial test is not sufficiently revealing and must be expanded. Second, classroom methods must become more interactive and “hands-on,” and more out-of-class support must be provided. Third, we must ensuring that grading of homework and exam problems be as transparent to the student as possible. Finally, choices must be made in the determination of a textbook. Each of these is examined in turn below.

Addressing the first, we are developing a more detailed preliminary test to be administered at summer orientation, which will both identify students should be taking PP to their advisors, and will give the instructor a more detailed picture of the students' initial ability. The new test will explicitly pose problems that address some of the issues with logic, visualization and geometry discussed above, rather than being limited to elementary physics and high-school algebra.

Addressing the second, we note that course scope and content are adequate, but its structure and method need improvement. For that, we turned to TAMUK's Center for Teaching Effectiveness Director, Dr. Jaya Goswami, to introduce group and interactive exercises into the course. Following our experience with Writing Across the Curriculum (WAC), we are introducing a writing component in this course. Students will be required to write essays both on problems and concepts in physics. We have also observed poor note taking skills--some students' notes consisted solely in what they copied from the blackboard. When they read their notes later they (not surprisingly) found them unintelligible and concluded that there's no value to taking notes. Thus it's not sufficient to tell them to take notes: they must be taught how. We are introducing methods drawn from Advancement Via Individual Determination (AVID) to improve note taking skills, and will encourage both note-taking in class and taking notes on reading the text, revising notes, and finally writing essays based on the notes. Finally, TAMUK has a strong Supplemental Instruction (SI) program, and we have already seen improvement in the last two semesters in which PP has had an SI leader.

Addressing the third, we will incorporate, with appropriate modifications, several techniques proposed by Kathleen Harper (2012) into our PP course beginning Fall 2013. Her observation that students perceive problem solving "as a recall task rather than a process" sums up several of the difficulties we've observed. We already grade problems on approach as well as correctness, but our method can be refined using Harper's techniques. In particular, she informs students at the outset that points are awarded for qualitative representation (usually diagram or graph), verbal identification of physical concepts, and algebraic statement of the equation (without numbers) gives the grading an organizational structure that will assist our students.

Addressing the fourth, we note that there is little agreement on the choice of a PP, as many variables, some regional, affect the choice. Some use the actual text used in the trig-based or calc-based IPS. We did not do this for two reasons. Many current IPS texts are too verbose: consequently, students have difficulty distinguishing fundamental principles from specific applications and side explanations. These texts are also very expensive, and being able to delay purchase for a semester is an advantage to many TAMUK students. One PP teacher wrote his own calc-based text (Cole, 1999). This is particularly appropriate when we consider that specific regional concerns must be addressed. We currently use the Schaum's Outline (Helpern, 1995), previously used in the PP course taught by the present author at UAB. It has the advantages of being trig-based, providing brief but illuminating explanations, and supplying many fully worked problems. The latter are useful for the important purpose of stimulating classroom discussion. (Why does the author take this step first when I prefer to take a different step first?)

However it is an outline, not ideal for naive students. The ideal text would be limited to basic Newtonian mechanics, would explain physical concepts in a thorough but concise manner, be accessible to the specific starting point of our students, and contain a large variety of fully worked (and fully explained) problems. At present we supply copious explanatory notes, and are in the process of expanding these and developing them into an textbook for the PP course that will include clear and lucid explanations, worked out problems, and detailed discussion of those points that our experience has shown to be most likely to be misunderstood by inexperienced students.

Most students who completed PP believe that this course aided their performance in IPS significantly, and their collective GPA supports their belief. The PP course is addressing a real need in helping students prepare for the demanding IPS.

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References

AVID: http://www.avid.org/hed_overview.html

Beckman, Mary P., "Collaborative learning: Preparation for the workplace and democracy," *College Teaching*, Vol. 38, No. 2 (1990).

Churukian, Alice D., "Interactive engagement in an introductory physics course: Learning gains and perceptions." Ph.D. Dissertation, Kansas State University, 2002.

Cole, Rodney. *So You Want to Take Physics*. Saunders, 1999.

Freeman, Scott, Haak, David, and Wenderoth, Mary Pat, "Increased course structure improves performance in Introductory Biology," *CBE Life Sci Education* , Vol. 10, No. 2 (Summer 2011).

Gill, P., "The physics/maths problem again," *Physics Education*, Vol. 34, No. 2 (1999).

Hake, Richard R. "Assessment of physics teaching methods." In *UNESCO-ASPEN workshop on active learning in physics*, University of Peradeniya, Sri Lanka 2002.

Harper, Kathleen A., "Grading homework to emphasize problem-solving process skills," *The Physics Teacher*, Vol. 50 (October 2012).

Helpern, Alvin. *Schaum's Outline of Beginning Physics: Mechanics and Heat.* New York: McGraw-Hill, 1995.

Hestenes, David, Wells, Malcolm, and Swackhamer, Gregg, "Force concept inventory," *The Physics Teacher*, Vol. 30 (March 1992).

Meltzer, David E., "The relationship between mathematics preparation and conceptual learning gains in physics: A possible 'hidden variable' in diagnostic pretest scores," *American Journal of Physics*, Vol. 70, No. 12 (2002).

Menken, Kate, "Teaching to the Test: How No Child Left Behind Impacts Language Policy, Curriculum, and Instruction for English Language Learners," *Bilingual Research Journal* Vol. 30, No. 2 (2006).

Saul, Jeffrey M., Beichner, Robert J., "An Activity-based Curriculum for Large Introductory Physics Classes: The SCALE-UP Project." University of Central Florida, Orlando, FL; and North Carolina State University, Raleigh, NC. people.rit.edu/svfsps/perc2001/Saul.doc

Selen, Mats, "Helping Under-prepared Students Learn Calculus-Based University Physics." web.hep.uiuc.edu/home/MATS/Talks/ aapt200_p100.ppt

Slavin, Alan, "Factors affecting student drop out from the university introductory physics course, including the anomaly of the Ontario double cohort," *Physics in Canada*, Vol. 64, No. 3 (2008).

Thornton, Ronald K., "Using the results of research in science education to improve science learning." Keynote address, International Conference on Science Education, Nicosia, Cyprus, 1999.