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The article on unification of couplings by Savas Dimopoulos, Stuart A. Raby and Frank Wilczek is very beautiful and clear, so let me just point out a slight historical inaccuracy. The authors remark parenthetically that "the Higgs mechanism is . . . a relativistic version of Fritz and Heinz London's superconducting electrodynamics."

I believe the real antecedent of the Higgs mechanism is the Debye–Hückel theory of screening of charge in electrolytes;[1] in this theory one sees explicitly how the $1/r$ in Coulomb's law is changed to Hideki Yukawa's $\exp(-r/b)/r$, which translates relativistically into giving mass to the gauge boson. Also, the superconductivity analogy should be credited to Philip W. Anderson;[2] it is very cryptic in the Londons' work.

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Figure 4 on page 28 of the October issue is said to represent screening that will lessen the electric field at large distances. A simple application of Gauss's law will show that a spherical configuration of dipoles surrounding a charge as shown produces *no* change in the electric field at large distances.

Since I am writing, permit me to express my admiration for Frank Wilczek's poetry.

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Is 'Workshop Physics' Not the Real Thing?

Priscilla W. Laws (December, page 24) writes about the Workshop Physics approach being used at Dickinson College. Since this approach is typical of a trend that is developing both at the college level and at the high school level, where most of my own teaching experience has been, it warrants a response. I believe this approach to be misconceived because it ultimately fails to convey the most important concepts that should be gained from an introductory physics sequence. The use of computers is in part the cause of this failure, which the computer usage then tends to disguise by creating an aura of sophistication.

Consider, for instance, Laws's description, given as an example of a beneficial outcome, of how a physics major arrived at the solution to a two-dimensional trajectory problem. The student recognized an analogy between horizontal wind gusts acting on a rocket and the sideways taps she had made on a moving bowling ball during an experiment. Although she was insightful in making this connection, her inability to solve the problem until she had thought of this analogy makes it evident that she had not yet grasped the fundamental idea of independent vector components.

Likewise, one of Laws's figures shows a spreadsheet analysis of student-obtained free-fall data that does, indeed, yield a straight-line distance-versus-time-squared graph, but only after the data have been linearized. It is unlikely that students who are described as still having trouble interpreting graphs would understand linearization. The computer is not just performing some tedious details. The computer calculations are obscuring those very details that the students need to work with, think about and finally understand. Working directly with a meter stick, a spark timer tape and a piece of graph paper would show much more immediately how the time-squared linearity arises from the fact that as time progresses the additional distance that the object falls during each time interval is itself increasing at a constant rate.

Similar concerns arise in regard to the use of computers in conjunction with teaching electric fields. A field mapping simulation, by the very virtue of the fact that it gives a result automatically, precludes the students from having to think about the underlying connections between charge distributions and the resulting flux

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lines. These simulations are then used for an empirical proof of Gauss's law. This approach ignores the connection between Coulomb's law and those rules for field mapping that are, at this level, precisely where the equivalence between Coulomb's law and Gauss's law arises.

Unfortunately, with the admirable aim of making physics more accessible, Workshop Physics has fallen into the trap of only teaching at the periphery of the discipline. Some of the deficiencies in this approach can be gleaned from the article itself. Why should students, who in the typical sequence would already be into their second semester, need a mechanical model with hoops and nails to understand the angular dependence of the electric flux through a surface? Perhaps, had the students been thinking more abstractly all along, they would have performed better than Laws reports they actually did on simple dc circuit problems that they could no longer experience kinesthetically. The issue here is not one of beginning gradually, but of not beginning at all.

We do a disservice to our students by teaching physics as something other than what it actually is. It is futile, even cruel, to coax students into becoming physics majors through false impressions, only to disillusion them later on. Physics is a difficult subject, and students must be made to confront these difficulties. There is no way to sneak up on it and catch it unawares. Students must be continually challenged. Even those who study physics only as part of their overall cultural education need to be confronted deeply if they are to carry away any substantial paradigms or any significant overview of its structure.

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Laws and her colleagues David Sokoloff and Ronald Thornton reply: We hope readers were not left with the impression that Workshop Physics students spend most of their time hitting bowling balls, playing with hoops and nails, and watching computers do pseudosophisticated calculations for them. They spend as much time as students in traditional calculus-based physics courses deriving equations, reading textbooks, solving problems and doing quantitative experiments. Since Workshop Physics students do as well or better on textbook problems as their cohorts taking traditional courses, we fail to see how we can be of accused of "only teaching at the periphery of the discipline."

The evidence is mounting that direct experience enhanced by student-directed computer analysis is a superior way to help students master important abstract concepts in physics. Thornton and Sokoloff, in testing over 4000 introductory physics students, found that even after completing a traditional study of kinematics the majority of them did not understand simple motion concepts and could not correctly associate simple velocity and acceleration graphs with the actual motions they describe.[1] The most effective way for students to learn these simple concepts and graphs is to use a microcomputer outfitted with a motion sensor and software that displays real-time graphs of their own body motions. Additional testing shows that even more students (over 85%) fail to answer simple force concept questions correctly after traditional instruction. Students who cannot understand even simple motion concepts will not be ready to deal effectively with the abstract languages of graphs and equations. The same is true for the large percentage of introductory physics students who have not yet been taught to engage in proportional reasoning.[2]

Of our students who begin two-dimensional motion studies by hitting bowling balls with batons and then apply theoretical considerations to the situation, 60–70% can correctly describe the path a rocket drifting sideways through space takes when its thrust engines are applied (see the article for details). Before we started to teach Workshop Physics, only 22% of our students could identify the correct path. David Hestenes and colleagues studied the performance of over a thousand students at different institutions on this same question and found a 20–25% correct-response rate to be a typical result for students of any instructor who did not use interactive, experience-based methods of teaching.[3] Even at Harvard University, before Eric Mazur instituted more interactive instructional techniques, only 44% of the students picked the correct path.[3] We would be the first to admit that recognizing that a whacked bowling ball and a drifting rocket to which thrust is applied follow paths of the same shape does not necessarily mean that a student has a deep theoretical understanding of the Newtonian description of two-dimensional motion. However, it is obvious to us that the vast majority of physics students receiving traditional instruction do not even have the base of experience needed to understand two-dimensional motion.

A third piece of evidence linking concrete experience with abstract ability can be gleaned from the learning styles of two Nobel laureates. When studying alpha-particle scattering, Ernest Rutherford had a model electromagnet grazing past a fixed one to simulate atomic scattering. Richard Feynman spent thousands of hours as a boy playing with electronic gadgets. And Galileo certainly loved working with gadgets. Would he have objected to using "new" technologies like spark timers or graph paper to study motion? If our average students came to the study of physics with such experiences and habits of inquiry, perhaps *then* we could skip the hands-on work and use of computers Edwin R. Schweber finds so antithetical to the teaching of abstract reasoning.

Students who have not had sufficient concrete experience with physical phenomena often drop physics or learn to memorize the algorithms for solving standard textbook problems so that they and their instructors can pretend that abstract reasoning is happening. Telling students they must reason abstractly or fail the course, as Schweber seems to suggest, reminds us of an old, rather sexist joke: A woman is wondering how Prokofiev could possibly write such beautiful music in a totalitarian country. She is told, "Lady, you too would write beautiful music if you had a gun pointed at your head."

We are committed to confronting students with direct experiences so that they can eventually taste the joys and heady power that abstract concepts and the language of mathematics afford in the exploration of the physical world.

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