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NINTH GRADE PHYSICS: A NECESSITY FOR HIGH SCHOOL SCIENCE PROGRAMS

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ABSTRACT: The traditional order in which science courses are taught in U.S. high schools is biology, chemistry, physics. The physics course usually is regarded as very difficult because it requires both high-level mathematical skills and high-level thinking skills; it is taught in the final year of high school to provide time for students to develop the necessary background in advanced mathematics and higher-order thinking skills. Research over the last 10 years indicates that an understanding of physics does not require, in fact, high-level mathematical skills and that some difficulties with physics are the result of students' misconceptions acquired at some earlier time. When these difficulties are addressed properly, it is possible to teach physics successfully to high school freshmen, providing them with considerable benefit for later science courses, particularly chemistry and biology.

The traditional order in which science courses are taught in U.S. high schools is biology, then chemistry, then physics (BCP). Biology usually is regarded as the study of living or once-living organisms, chemistry as the study of matter, and physics as the study of concepts such as force, energy, and motion required for the understanding of all science. The primary contemporary rationale for this sequence of teaching science courses is that the mathematical and thinking skills required in physics are believed to be at a higher level than those required for chemistry and biology. According to this rationale, teaching physics in the senior year provides time for students to develop the required mathematical and higher-order thinking skills.

As noted by Sheppard and Robbins, the BCP order and the rationale for it were set in 1893 by the Physical Science Subcommittee of the Committee of Ten, established by the National Education Association to recommend a course of study for U.S. high schools.[1] The subcommittee reported that the biology-chemistry-physics order

[1]Keith Sheppard and Dennis Robbins, "Lessons from the Committee of Ten," *The Physics Teacher* 40 (2002): 426.

was not logical because physics was the most fundamental science, but that its members believed that the need for certain mathematical skills and thinking skills in physics outweighed the more fundamental nature of physics.

Interestingly enough, as Sheppard and Robbins also point out, the Committee of Ten did not follow the recommendations of its Subcommittee on Physical Sciences.[2] Rather, submitting that physics was the more fundamental science, it recommended that physics be taught first.[3] However, the recommendations of the Subcommittee on Physical Sciences to teach biology, chemistry, and physics in that order have generally been followed in the United States, although not in the rest of the world.

It is both interesting and timely to examine changes over the last century in the sciences themselves, in the way that science is regarded in society, and in the manner in which science is taught. In 1893 many scholars and teachers regarded physics as a field that was complete. Newton's laws and Maxwell's equations had adequately explained mechanics and electricity and magnetism. Gibbs had published his monumental work on thermodynamics, and that subfield was regarded as well understood. The Periodic Table had been developed, helping to organize all chemistry. Pasteur had learned to conquer disease, and Darwin had explained evolution. What more could be understood about science except to fill in the details? Certainly, from the viewpoint of 1893, science could be taught as a single course in high school, and the choice of which one to teach was not serious; blanks could be filled in during the college years for those students who needed a more complete picture.

The view of science expressed in 1893 clearly was incorrect. The basic sciences of biology, chemistry, and physics have undergone revolutionary changes in understanding and enormous growth during the last century, and science occupies a much more significant role in society at the beginning of the 21st century than it did at the end of the 19th century. Symbolic of this change is that the amount of high school science required for graduation from high school in a college preparatory program has increased from 1 unit (out of a total of 16 units of study and chosen from physics, chemistry, or biology) in 1893[4] to 3 or sometimes 4 units (out of perhaps 20 to 24 units, including 2 chosen from physics, chemistry, and biology plus one ad-

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[2]Ibid.

[3]National Education Association, *Report of the Committee on Secondary School Studies* (Washington, DC: Bureau of Education, 1893).

[4]Ibid.

ditional science course) in 2004.[5] Thus, although the total number of courses to be taken in high school has increased by 25 to 50 percent (from 16 Carnegie units to 20 to 24 Carnegie units) over the last century, the number of science courses has tripled or quadrupled.

The true situation is more easily understood when the nature of the science courses themselves is considered. The increase in scientific knowledge during the last century has led to a corresponding increase in the amount of material included in basic high school science courses. The course content taught in 1893 is still taught today, but that content accounts for perhaps 15 percent of the modern courses. The total amount of science material to be taught and learned in high school has expanded by a factor of perhaps 20 (seven times as much material in each course multiplied by three courses rather than one), while the time allocated for this teaching and learning has perhaps doubled from one-sixteenth of four high school years in 1893 to one-eighth today.

Indeed, a reasonable argument can be advanced that with the increase in the number and performance level of high school sports and extracurricular activities over the last century, the time available for academic pursuits in high school is much less than it was a century ago. If schools are to successfully meet the challenge of teaching and learning perhaps 20 times as much material in something less than twice as much time, they must develop a more deliberate curriculum.

In terms of the development of the branches of sciences across the last century and, especially, over the last 50 years, biology has developed in a way that increasingly uses concepts from both chemistry and physics. Also, chemistry increasingly uses concepts normally taught in physics. Physics, on the other hand, requires no concepts at all from either chemistry or biology. Figure 1 illustrates this situation. As the figure suggests, in terms of curriculum efficiency, physics should be taught first, then chemistry, and then biology, because the chemistry and biology courses could draw on the concepts

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[5]As examples, New York State currently requires 22 Carnegie units, including 1 unit of life science and 2 units of physical science (http://www.emsc.nysed.gov/part100/pages/1005a.html). North Carolina requires 20 Carnegie units, including 3 units of science for a college preparatory diploma plus any local requirements (http://www.ncpublicschools.org/student_promotion/gradreq.html). South Carolina requires 24 Carnegie units, including 1 unit of physical science (required for high school freshmen but not counted as a lab science for college admission by the Commission on Higher Education) plus 3 units of laboratory science (http://sde.state.sc.us). The College Board is currently recommending a minimum of 3 Carnegie units of science, including biology and chemistry or physics and an advanced science (http://www.collegeboard.com/article/0,3868,2-7-0-33,00.html).

Figure 1. Overlap of Concepts in High School Physics, Chemistry, and Biology Courses

Physics Concepts Used in Chemistry	Chemistry Concepts Used in Biology
Atomic physics/quantum mechanics	Chemical equations
Kinetic and potential energy	Stoichiometry
Force	Thermodynamics
Electrostatic interaction	Kinetics
Pressure	Catalysis
Heat	Osmosis
Waves/light	Chemical bonding

already taught in the previously taken physics and chemistry courses. This article analyzes the pedagogical soundness of first teaching physics, then chemistry, and then biology, with particular attention to the national science standards[6] and the curriculum standards adopted for these subjects by various states.

TRADITIONAL CONCERNS ABOUT TEACHING PHYSICS

Before suggesting which grade level is appropriate for teaching physics, it is important to address the traditional concerns concerning the level of mathematics and the level of thinking required to understand physics. Positioning physics at the beginning of the science curriculum would be pointless if the required mathematics could not be taught until the end of the mathematics curriculum. If thinking skills at the highest levels of Bloom's Taxonomy are required to comprehend physics and students cannot acquire those skills until age 17 or later, perhaps physics is best regarded as a course suited only for the brightest students at the highest level of high school. An analysis of these concerns permits an answer to the question "At what grade level in the high school science curriculum is physics best taught?"

The Mathematics Required to Understand High School Physics

The National Council of Teachers of Mathematics (NCTM) has advanced standards for the teaching of mathematics that are parallel to the national science standards. The NCTM mathematics standards are often used by states in the standard-setting process in much the

[6]National Committee on Science Education Standards, National Research Council, *National Science Education Standards* (Washington, DC: National Academy Press, 1996). Available: http://www.nap.edu/catalog/4962.html.

same way that the national science standards are used. Because state standards for science and mathematics courses are virtually all derived from the national science standards and the NCTM standards, the standards established by various states are far more similar than different. Differences between state standards tend to be in the level of understanding to be achieved by students rather than in the nature of the topics taught. States implement and enforce educational standards primarily through the use of standardized tests with standardized grading. States opting for relatively low standards use tests that ask questions and permit answers at a relatively low level of understanding, such as definitions. States opting for high standards usually use tests that ask questions that require a high level of understanding, perhaps solving a new problem or drawing a conclusion in a new context using concepts that should have been taught. In each case the state regards the topic as learned if students successfully answer the relevant question on the examination, although the level of understanding required of students in the two cases differs substantially.

The issue of whether or not students have actually learned the substantive content covered in the state standards and what level of understanding they have achieved is of substantial concern in education generally and in science education in particular. Nevertheless, this topic merits additional inquiry. States seem to agree on the grade level at which various concepts should be taught, and, for the moment, a necessary assumption is that the mathematical and physical concepts to be discussed have been assigned at appropriate grade (age) levels by the national science standards and the NCTM standards. The issue here is to establish the grade level at which the various mathematical concepts are supposed to be taught and to verify that the mathematical concepts have been included in the mathematics curriculum before they are required for use in physics. Comparing the New York State core curricula in mathematics and physics provides a reasonable and convenient way to make this determination.

The mathematical concepts required in the study of New York State Regents Physics and Chemistry are presented in Figure 2. For the purposes of the figure, physics has been divided into Conceptual Physics and Regents Physics (this division will be convenient later in this article). It is worth noting that the mathematical concepts included in this figure represent my own opinion as an experienced chemistry and physics teacher. Likely, few physics teachers would delete items from this list; however, other physics teachers reasonably might add to it.

Understanding that the information in Figure 2 represents the opinion of a successful physics teacher, virtually all of the mathe-

Figure 2. Mathematical Concepts Required in New York State Regents Physics and Chemistry

Conceptual Physics	Regents Physics	Chemistry
Arithmetic (5, 6)* Proportions (5, 6) Scientific notation (5, 6) Variables (5, 6) Constants (5, 6) Simple equations in one unknown (5, 6) Powers and roots (7, 8) Order of operations (5, 6) Graphing (5, 6) Functions (5, 6) Units (7, 8)	Conceptual physics plus • Basic trig functions and inverses (7, 8) • Pythagorean theorem (5, 6) • Vectors (10 or 11)	Regents physics plus • Linear equations 2 unknowns • Quadratic equations (7, 8) • Quadratic formula • Logarithms (10 or 11) • Antilogarithms

*Numbers in parentheses indicate the grade level at which the topic is taught in the New York State mathematics core curriculum.

matical concepts required for the study of physics are taught in the 5th and 6th grade. Indeed, only "powers and roots," "units," and "basic trigonometric functions" are taught in the 7th and 8th grade, and "vectors" appears in the second mathematics course in high school, normally taught in grades 10 or 11. The mathematical concept of vectors is very useful in physics but is covered at the end of the second high school mathematics course and often is not taught at all. Thus, physics teachers normally teach vectors at the beginning of the physics course, and they otherwise use only mathematical concepts taught in or before 8th grade. Students' perceived lack of mathematical concepts should not be a barrier to teaching physics in the 9th or even the 8th grade, because virtually all mathematical concepts should have been taught well before then, and the remaining mathematical concepts easily may be taught at the beginning of the physics course. As Figure 2 indicates, chemistry actually uses more advanced mathematical concepts than physics.

Again, that a topic is present in a curriculum does not mean that it has been taught or that students have learned it. Indeed, high school and college teachers of both physics and chemistry routinely complain that students are unable to apply mathematical concepts taught in mathematics classes to physics and chemistry problems. Many physics and chemistry teachers (including myself) spend something like 10 to 15 percent of the science course time reteaching concepts that were taught and successfully assessed in previous or concurrent mathematics courses. Further, both high school and college science teachers observe that students will not admit to having learned anything in any previous course—including previous science courses—unless it is reviewed and explained again in the current course. This problem may be a legitimate transference problem or simply a pervasive strategy by students to reduce their workload.

Conceptual Requirements in Physics

Given that no pedagogical reason (specifically, lack of mathematical understanding) exists not to teach physics as a first high school science course, an appropriate consideration is the possibility that the conceptual requirements of physics are beyond the abilities of 8th and 9th grade students.

Paul Hewitt at the City College of San Francisco was one of the first physics teachers to realize that extensive mathematics is not a necessary prerequisite to the teaching of physics concepts. Currently in its ninth edition, his *Conceptual Physics* was first published in 1971.[7] This text is used in both high school and college physics courses and does not assume that students need extensive prerequisite mathematical development. In continuous publication for more than 30 years, it must be regarded as one of the most successful physics books ever written.

A second conceptual approach developed specifically for high schools is *Active Physics,* developed by Dr. Arthur Eisenkraft of the Fox Hill High School in Bedford (Westchester County), New York, in conjunction with the American Association of Physics Teachers and the American Institute of Physics.[8] The *Active Physics* materials were developed specifically for students at the 9th or 10th grade levels.

A list of the concepts required for the New York State Regents Physics course is presented in Figure 3. Many of the same concepts are presented in the New York State Grade 5–8 and Grade 1–4 curricula, and, for comparative purposes, these concepts have been included in the figure. The concepts presented in both Hewitt's *Conceptual Physics* and the *Active Physics* programs also have been included for comparison.

A first impression from the information in Figure 3 may be that a surprisingly large number of the Regents Physics topics are included in the elementary and middle school science curricula. A second impression is how well the Hewitt *Conceptual Physics* course covers the NYS middle school curriculum in physics (or, conversely, how much of the Hewitt course is contained in the NYS middle

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[7]Paul C. Hewitt, *Conceptual Physics,* 9th ed. (Needham, MA: Benjamin Cummings, 2002), for college use; Paul C. Hewitt, *Conceptual Physics: The High School Program* (Needham, MA: Prentice Hall, 2002), for high school use.

[8]Arthur Eisenkraft, *Active Physics* (Armonk, NY: It's About Time, Inc., 2000). Available: http://www.its-about-time.com/htmls/ap.html.

Figure 3. Comparison of Physics Curricula

New York State Regents Core Curriculum Topics	NYS 5–8	NYS 1–4	*Conceptual Physics*	*Active Physics*
Mathematics				
Vectors			Yes	Yes
Graphs			Yes	Yes
Mechanics				
Position	Yes	Yes	Yes	Yes
Velocity	Yes		Yes	Yes
Speed	Yes		Yes	Yes
Acceleration	Yes		Yes	Yes
Newton's first law	Yes		Yes	Yes
Force	Yes	Yes	Yes	Yes
Newton's second law	Yes		Yes	Yes
Free body diagrams				
Newton's third law	Yes		Yes	Yes
Equilibrium				
Friction	Yes	Yes		Yes
Projectiles	Yes		Yes	Yes
Momentum			Yes	Yes
Impulse-momentum theorem				Yes
Conservation of momentum				Yes
Energy	Yes		Yes	Yes
Power				Yes
Springs				
Pendulum				Yes
Gravity	Yes	Yes	Yes	Yes
Rotational motion			Yes	Yes
Potential energy	Yes			Yes
Kinetic energy	Yes			Yes
Conservation of energy	Yes			Yes
Conversion of energy	Yes			Yes
Work-energy theorem	Yes			Yes
Electricity and Magnetism				
Charge	Yes		Yes	Yes
Electrostatic force	Yes		Yes	Yes
Current	Yes		Yes	Yes
Voltage	Yes		Yes	Yes
Resistance			Yes	
Resistance of wires				
Ohm's law				
Electric field	Yes			
Electrical energy	Yes			Yes
Electrical power				Yes
Magnetism	Yes	Yes	Yes	Yes
Magnetic field	Yes			Yes
Series circuits				Yes
Parallel circuits				Yes
Voltmeters				
Ammeters				

(continued)

Figure 3. Comparison of Physics Curricula *(continued)*

New York State Regents Core Curriculum Topics	NYS 5–8	NYS 1–4	*Conceptual Physics*	*Active Physics*
Waves				
Longitudinal			Yes	Yes
Transverse			Yes	
Electromagnetic	Yes		Yes	Yes
Wavelength				Yes
Period				Yes
Frequency				Yes
Speed				Yes
Amplitude				Yes
Phase				
Sound	Yes		Yes	Yes
Resonance			Yes	Yes
Interference				Yes
Reflection			Yes	Yes
Index of refraction				Yes
Refraction	Yes		Yes	Yes
Diffraction				Yes
Standing waves				Yes
Atomic Physics				
Energy level diagram			Yes	
Line spectra			Yes	Yes
Photons			Yes	
Energy is equivalent to mass				
Wave particle duality				
Charge is quantized			Yes	
Standard Model				
Subnuclear particles, quarks				
Antiquarks				
Leptons				
Anti-leptons				

school curriculum). Clearly, those who framed the middle school science standards and curricula intended that physics concepts be taught at that level and believed that middle school students are capable of learning these concepts. Also clear is that middle school students do not learn the concepts sufficiently, because Hewitt still teaches the same concepts at the college level. At this point one could reasonably argue that the concepts are not learned in middle school because the students are not yet cognitively ready for them. A second reasonable argument, however, is that middle school students already may have acquired incorrect or insufficient understandings of the physics concepts, which they retain as they grow older, and that the teaching efforts at the middle school, high school, and beginning college levels simply are inadequate to correct the situation. Approaches to teaching have been developed, however, that can correct these misconceptions. To the extent that these approaches are successful with 9th graders, no reliable reason exists to believe that the concepts are beyond those students' reach.

DIFFICULTIES WITH CURRENT TEACHING APPROACHES

The mathematics and conceptual perspectives provide no sufficient reason not to offer physics as a first science course in the 8th or 9th grade. However, a reasonable question arises about the efficacy of current approaches to the teaching of physics to K–12 students generally (lecture combined with laboratory), given that students often have considerable difficulty understanding elementary college physics.[9]

In work that can only be described as visionary, L. P. Benezet, who in the late 1930s was superintendent of schools in Manchester, New Hampshire, described a successful hands-on approach to teaching mathematics.[10] Benezet clearly showed that rote memorization techniques commonly used to teach elementary school mathematics were counterproductive. He emphasized that students had no need for such skills (such as learning multiplication tables), other than possibly making change, in their life outside of school until the 7th grade, and thus no need justified their acquisition of this knowledge before that time. He abolished all such rote memorization from mathematics teaching in the Manchester schools until the beginning of the 7th grade. Rather, the district's teachers concentrated on the development of mathematical logic in conjunction with such skills as keeping and telling time and dates. Telling time requires, of course, counting modulo 60, 12, and 24, and dates require counting modulo 30, 31, and 28. Students thereby acquired the skill of counting in different modulus number systems without being taught to do so explicitly. When the students began 7th grade and the various number system topics were addressed explicitly, students found that they al-

[9]Ibrahim Halloun and David Hestenes, "The Initial Knowledge State of College Physics Students," *American Journal of Physics* 53 (1985): 1043–1055; Richard R. Hake, "Promoting Student Crossover to the Newtonian World," *American Journal of Physics* 55 (1987): 878; Richard R. Hake, "Socratic Pedagogy in the Introductory Physics Lab," *The Physics Teacher* 30 (1992): 546; Richard R. Hake, "Survey of Test Data for Introductory Mechanics Courses," *AAPT Announcer* 24 (1994): 55.

[10]L. P. Benezet, "The Teaching of Arithmetic I: The Story of an Experiment," *Journal of the National Education Association* 24 (1935): 241–244; L. P. Benezet, "The Teaching of Arithmetic II: The Story of an Experiment," *Journal of the National Education Association* 24 (1935): 301–303; L. P. Benezet, "The Teaching of Arithmetic III: The Story of an Experiment," *Journal of the National Education Association* 25 (1936): 7–8.

ready knew the concepts and could demonstrate competence after only a couple of months. A comparison of the performance of students taught using the new technique versus students taught using the traditional approach clearly demonstrated that the traditional students had few problem-solving skills, whereas those taught using the new technique excelled at problem solving and performed at an equivalent level in the memorized material, such as multiplication tables, when compared with the traditionally taught students. This visionary work has lain dormant for nearly 70 years.

In the early 1970s, Arnold Arons at the University of Washington showed that physics concepts were not effectively taught using conventional lecture techniques, but could be taught using what are now called interactive techniques.[11] Interactive techniques require that the student actively engage the topic being taught. Traditional (passive) techniques require the student to watch and listen and to do assigned problems. As an example, trajectories may be taught passively by drawing diagrams on the blackboard, doing sample calculations, and having the students do problems of various types. Taught actively, students are presented with a device capable of launching a projectile and asked to calculate the impact point of the projectile and then compare their calculation with the measured impact point. This idea can be expanded further into what might be called an interactive-engagement technique, in which students could be asked to design a device capable of launching a projectile to a predetermined target, perhaps in competition with other students. Each case requires learning how to calculate trajectories, but in the passive techniques the calculation concludes the lesson. In the interactive and interactive-engagement techniques, calculation is a necessary means to another end. Interactive or interactive-engagement techniques are focused on students' learning of the material in order to achieve success. Relevant activities must be carefully designed to ensure that the lessons to be learned are actually the lessons that are taught.

About 30 years ago David Hestenes at the University of Arizona began investigating why college students in beginning engineering classes had so much difficulty with introductory physics, especially with Newtonian mechanics, the traditional starting point for a rigorous education in physics. Hestenes found that the primary cause was

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[11]A. B. Arons, "Toward Wider Public Understanding of Science," *American Journal of Physics* 41 (1972): 769–782; A. B. Arons, " 'Toward Wider Public Understanding of Science' Addendum," *American Journal of Physics* 42 (1974): 157–158; A. B. Arons, "The Various Language," in *Teacher's Handbook* (New York: Oxford University Press, 1977); A. B. Arons, *A Guide to Introductory Physics Teaching* (New York: Wiley, 1990).

not students' difficulty with mathematics, but rather that the physics concepts themselves countered the students' preconceived ideas about how the world works. However the students developed their intuition, by the time they got to college, physics was counterintuitive.[12] Apparently K–12 teaching either had fostered the students' incorrect intuition or had failed to overcome an incorrectly developed intuition.

Hestenes proposed that a primary measure of success for an introductory college-level physics course should be the extent to which students developed a correct understanding (intuition) of the way that the world works in terms of Newtonian mechanics. Hestenes, with colleagues Malcolm Wells and Gregg Swackhamer, developed and standardized (validated) a procedure to measure the extent to which the effort to revamp student intuition had succeeded in a physics course; they called the measure the Force Concept Inventory.[13] Hestenes and another colleague developed a method of systematically evaluating the effectiveness of the teaching in a physics course using the techniques of the Force Concept Inventory.[14]

The Force Concept Inventory is a short multiple-choice test to determine whether or not students correctly understand the fundamental concepts of Newtonian mechanics. Common misconceptions are provided as distracters along with correct answers to the situations presented by the questions. Thousands of physics students at all levels have taken this test. Results indicate that nearly all students hold their misconceptions through high school and beginning college physics programs.[15] The source of these misconceptions and the reason that they are so difficult to correct is one of the great puzzles in Physics Education Research (PER).

Richard Hake, recently retired from the University of Indiana, also pointed out students' difficulty with physics concepts[16] and pi-

[12]Ibrahim Halloun and David Hestenes, "Common Sense Concepts About Motion," *American Journal of Physics* 53 (1985): 1056–1065.

[13]David Hestenes, Malcolm Wells, and Gregg Swackhamer, "Force Concept Inventory," *The Physics Teacher* 30 (1992): 141–151; David Hestenes and Malcolm Wells, "A Mechanics Baseline Test," *The Physics Teacher* 30 (1992): 159–166; David Hestenes, Malcolm Wells, and Gregg Swackhamer, "A Modeling Method for High School Physics Instruction," *American Journal of Physics* 63 (1995): 606–619.

[14]David Hestenes and Ibrahim Halloun, "Interpreting the Force Concept Inventory," *The Physics Teacher* 33 (1995): 502, 504–506.

[15]Ibrahim Halloun and David Hestenes, "The Initial Knowledge State of College Physics Students," *American Journal of Physics* 53 (1985): 1043–1055; David Hestenes and Ibrahim Halloun, "Interpreting the Force Concept Inventory," *The Physics Teacher* 33 (1995): 502, 504–506.

[16]Richard R. Hake, "Interactive-Engagement vs. Traditional Methods: A Six Thousand Student Survey of Mechanics Test Data for Introductory Physics Courses," *American Journal of Physics* 66 (1998): 64–74.

oneered interactive-engagement education methods in physics education, introducing the so-called Socratic Dialog Inducing Labs.[17] In the Socratic Dialog Inducing framework, students are asked to perform a simple experiment in which an apparatus behaves in a way conflicting with common misconceptions about mechanics. The student then formulates a question that will help explain the conflict. The student's question is answered with another question (Socratic dialog) or a suggestion for a further experiment with the apparatus. This process is repeated until the student correctly understands the problem and its solution.

Hake also provided an extensive justification for the results obtained using the modeling and interactive-engagement methods in both high school and college. Hake, using the Force Concept Inventory as a measure of success, concluded that the modeling and interactive-engagement methods were both effective in overcoming the conceptual difficulties caused by students' incorrect worldview. He also found that many students can pass both high school and introductory college physics courses with their incorrect worldviews intact.[18]

The work of Hestenes and his students has not been accepted without criticism. Huffman and Heller did not question the utility of the Force Concept Inventory as a qualitative tool for pointing out a serious difficulty with physics instruction, but they did not find it useful as a quantitative tool for diagnostic testing or as a measure of the success of a physics course.[19]

Hestenes, Wells, and Swackhamer proposed a modeling method for high school physics instruction as another hands-on method of teaching physics that was effective in overcoming the conceptual difficulties uncovered by the Force Concept Inventory.[20] Gregg Swackhamer, one of the researchers, was at the time a high school physics teacher at Glenbrook North High School in Illinois. This program has undergone continual development, primarily at the University of Arizona, and is recognized today as one of the premier physics educa-

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[17]Richard R Hake, "Socratic Pedagogy in the Introductory Physics Lab," *The Physics Teacher* 30 (1992): 546.

[18]Richard R. Hake, "Interactive-Engagement vs. Traditional Methods: A Six Thousand Student Survey of Mechanics Test Data for Introductory Physics Courses," *American Journal of Physics* 66 (1998): 64–74. A more extensive list of references is available at http://media4.physics.indiana.edu/~sdi/.

[19]Douglas Huffman and Patricia Heller, "What Does the Force Concept Inventory Actually Measure?" *The Physics Teacher* 33 (1995): 138–143.

[20]David Hestenes, Malcolm Wells, and Gregg Swackhamer, "A Modeling Method for High School Physics Instruction," *American Journal of Physics* 63 (1995): 606–619.

tion programs in the world. Extensive training opportunities in modeling techniques are available for high school teachers, along with extensive support.[21]

Given that the Force Concept Inventory has been used effectively for 10 years, and the modeling and interactive-engagement methods have been used for almost as long, incorrect worldviews must be understood as a major source of the difficulty many K–12 students experience in physics. Also clear is that traditional teaching techniques do not correct these incorrect worldviews and that nontraditional, interactive teaching techniques *can* correct these incorrect worldviews.

Thus there is no substantive reason not to teach physics as early as the 9th or perhaps even the 8th grade because of students' lack of mathematics skills or inability to comprehend the subject matter. A difficulty has been uncovered, however, concerning the incorrect worldview held by many students despite their successful performance in the high school physics course. Teaching must yield a correct physical intuition, and that teaching can be done by using interactive-engagement or modeling teaching methods. In addition, teachers must find the source of the incorrect worldview and modify their teaching so that it fosters a correct worldview instead.

CURRENT WORK ON PHYSICS FIRST

An active movement in physics teaching called "Physics First" advocates teaching physics to high school freshmen using interactive techniques. Physics First is championed by, among others, Leon Lederman.[22] Approximately 100 schools, many of them private, are believed to be using the Physics First approach. Physics teachers at eight of these schools were contacted informally for comment about this program. All reported success with the program both in increased enrollment in science courses by students in grades 10 through 12 and better preparation of students subsequently enrolled in chemistry and biology courses. None of these teachers reported any difficulty with the 9th graders' lack of mathematics skills; some, however, reported "growing pains" associated with introducing the program because the entire school needed to convert to Physics First in order to avoid scheduling problems. None of these teachers was

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[21]Further information is available at http://modeling.asu.edu/modeling-HS.html.

[22]L. M. Lederman, "A Science Way of Thinking," *Education Week* 16 (June 1999); available online at http://www.edweek.org/ew/1999/40leder.h18; L. Lederman, "Physics First," *APS Forum on Education Newsletter* (Spring 2001); L. Lederman, "Revolution in Science Education: Put Physics First," *Physics Today* 54 (2001): 11–12; available online at <http://physicstoday.org/pt/vol-54/iss-9/p11.html>.

willing to return to the previous system. All of these schools used either Hewitt's *Conceptual Physics* or the *Active Physics* series of texts. Still, a third approach is available: *Comprehensive Conceptual Curriculum in Physics (C^3P),* developed by Richard Olenick of the Physics Department at the University of Dallas.[23]

PHYSICS IN GRADES K–8

As noted, a major difficulty with high school physics education is an incorrect worldview held by high school students and beginning college students. That incorrect worldview is either propagated or generated in the K–8 curriculum; thus that program merits attention. Figure 4 displays the relationships among the New York State Core Curriculum for Physics, the New York State Core Curriculum for Science Grades 5–8, and the middle school science curriculum recommended by the National Academy of Sciences.[24]

As Figure 4 indicates, the curriculum recommended by the National Academy of Sciences is substantially more complete than that adopted by New York State for use in middle school and also includes a number of topics not included in the New York State Regents Physics (high school) curriculum. As a point of information, the physics topics recommended by the National Academy of Sciences for inclusion in the science curriculum in grades 1 through 6 are included as Figure 5.[25]

The National Academy of Sciences has supported extensive work in the teaching of science in kindergarten through 8th grade. Ramon Lopez and Ted Schultz in their review of this research concluded that the best approach to science education in the elementary school was the use of kits that are provided to elementary school teachers.[26] The difficulty addressed by Lopez and Schultz (and the National Academy of Sciences, which supported the development of the kits) is that elementary school teachers traditionally are not as interested in or as knowledgeable about science as they

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[23]http://phys.udallas.edu/. Detailed material regarding this approach is available only to schools willing to conduct or send teachers to a 45-to-60-hour training workshop. This approach is not discussed here because no one contacted had used it, and information concerning the program is difficult to obtain.

[24]National Academy of Sciences, *Resources for Teaching Middle School Science* (Washington, DC: National Academy Press, 1998). Available: http://bob.nap.edu/html/rtmss/.

[25]National Academy of Sciences, *Resources for Teaching Elementary School Science* (Washington, DC: National Academy Press, 1996). Available: http://bob.nap.edu/books/0309052939/html/.

[26]Ramon E. Lopez and Ted Schultz, "Two Revolutions in K–8 Science Education," *Physics Today* 54 (2001): 44.

Figure 4. Middle School Physics Curricula

New York State Core Curriculum for Physics	NY State Core Curriculum for Science, Grades 5–8	National Academy of Sciences Middle School Curriculum*
Mathematics		
Vectors		1.75
Graphs		1.28
Mechanics		
Position	Yes	1.14
Velocity	Yes	1.14
Speed	Yes	1.14
Acceleration	Yes	1.14
Newton's first law	Yes	1.14
Force	Yes	1.14, 1.29
Newton's second law	Yes	1.14
Free body diagrams		
Newton's third law	Yes	1.14
Equilibrium		
Friction	Yes	1.3
Projectiles	Yes	
Momentum		1.30
Impulse-momentum theorem		
Conservation of momentum		1.34
Energy	Yes	1.3
Power		1.14
Springs		
Pendulum		1.80
Gravity	Yes	1.14
Rotational motion		1.109
Potential energy	Yes	1.14
Kinetic energy	Yes	1.14
Conservation of energy	Yes	1.14
Conversion of energy	Yes	1.46
Work-energy theorem	Yes	1.14
Electricity and Magnetism		
Charge	Yes	1.9
Electrostatic force	Yes	
Current	Yes	1.2
Voltage	Yes	1.2
Resistance		1.2
Resistance of wires		
Ohm's law		
Electric field	Yes	1.2
Electrical energy	Yes	
Electrical power		
Magnetism	Yes	1.2
Magnetic field	Yes	1.2
Series circuits		1.25
Parallel circuits		1.25
Voltmeters		
Ammeters		1.25

(continued)

Figure 4. Middle School Physics Curricula *(continued)*

New York State Core Curriculum for Physics	NY State Core Curriculum for Science, Grades 5–8	National Academy of Sciences Middle School Curriculum*
Waves		
Longitudinal		
Transverse		
Electromagnetic	Yes	1.15
Wavelength		
Period		
Frequency		
Speed		
Amplitude		
Phase		
Sound	Yes	1.15
Resonance		1.15
Interference		
Reflection		1.15
Index of refraction		
Refraction	Yes	1.15
Diffraction		
Standing waves		
Atomic Physics		
Energy level diagram		
Line spectra		
Photons		
Energy is equivalent to mass		
Wave particle duality		
Charge is quantized		
Standard Model		
Subnuclear particles, quarks		
Antiquarks		
Leptons		
Anti-leptons		
		Electromagnetism
		Electromagnetic induction
		Heat
		Archimedes' principle
		Bernoulli's principle
		Hearing
		Light
		Optics
		Vision
		Surface tension
		Aerodynamics
		Pressure
		Capacitance
		Polarization
		Diodes
		Transistors

*Numbers are the assignment numbers at which the topic is treated in the NAS curriculum. Words in this column are topics included in the NAS curriculum but not included in the New York State Regents Physics curriculum.

Figure 5. Physics Concepts Taught in Grades 1–6 (National Academy of Sciences)

Physics Concept	Grade	NAS Module
Motion	1, 2	3.1 Balance and Motion
Weight	2	3.2 Balance and Weighing
Recoil, motion	K, 1	3.3 Balls and Ramps
Electrical circuits	4, 5	3.6 Circuits and Pathways
Electrical circuits	4	3.7 Electric Circuits
Energy transfer	5	3.8 Energy Sources
Levers and pulleys	5, 6	3.12 Levers and Pulleys
Levers and pulleys	2, 3	3.13 Lifting Heavy Things
Electricity and magnetism	3, 4	3.15 Magnetism and Electricity
Electricity and magnetism	6	3.16 Magnets and Motors
Sound	3, 4	3.21 Physics of Sound
Position, motion, force (push or pull)	4	3.22 Relative Position and Motion
Sound	2, 3	3.25 Sound
Sound	3	3.26 Sounds
Supplemental		
Light	5, 6	3.33 Color and Light
Electrical circuits	3, 4, 5	3.35 Electrical Circuits
Electricity and magnetism	4, 5, 6	3.36 Electromagnetism
Energy transfer	2	3.37 Energy—How you use different forms of energy
Length, volume	1, 2, 3	3.40 Length and Capacity
Lenses and mirrors	5, 6	3.41 Lenses and Mirrors
Viscosity, cohesion	3, 4, 5	3.43 Looking at Liquids
Diffusion	1, 2, 3	3.42 Liquid Explorations
Motion	4	3.44 Motion: How Moving Objects Interact
Simple machines	5, 6+	3.47 Simple Machines
Sound	2, 3, 4	3.50 Sound
Force (directional)	5, 6+	3.51 STAR Flight Lab

are in more traditional elementary school teaching areas such as reading. The science kits come ready to use, with complete directions and sufficient supplies for students to execute the unit. As Lopez and Schultz point out, however, if the kits are used, some provision must be made to maintain them—replace the consumables and any equipment that was lost, and repair or replace whatever was broken. Someone knowledgeable in science must maintain the kits. An expectation that every elementary school teacher perform this function, which is both time consuming and tedious and requires a level of science expertise not every elementary school teacher may have, simply is untenable and impractical. Some school districts have addressed this situation by establishing a central kit maintenance facility or by contracting for kit maintenance with an outside organization. This approach has been in use for only a few years; no research has been published as to how well it works.

Another approach that has much face value is the co-teaching of physics and mathematics. In this approach the physics and mathematics courses are combined into one course with enough time scheduled to teach both. Students receive two grades and two credits. Colleges have implemented this approach for students needing remedial work using introductory chemistry and college algebra;[27] the approach has resulted in the publication of a textbook that seems appropriate for use in high school.[28] A benefit of this approach to the mathematics program is that students learn math concepts they need immediately and that retention of the mathematics concepts is likely improved. This prospect is consistent with the work of Benezet nearly 70 years ago.[29] A benefit to the science program is that the seeming transference problem is eliminated or at least reduced. The course as a whole benefits from some consolidation between the curricula primarily because the extended time available permits a much more reflective approach to the engagement with subject matter from both courses. The general approach of combining chemistry and math instruction is also being pursued via Project Numina at the University of North Carolina at Wilmington, using an interactive approach with handheld computers.[30] Although this work is proceeding at the college level and primarily in chemistry, the approach appears to be directly applicable to physics, with similar benefits to be expected.

CONCLUSIONS AND IMPLEMENTATION RECOMMENDATIONS

Clearly K–12 science education must change—and soon. The amount of technical information available to humanity doubles

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[27]M. O'Brien and D. Chalif, *CHEMATH: A Learning Community in Science and Math*, ERIC Accession ED 335 157 (1991); D. E. Nickles, *Chemist* 7 (1996); S. A. Angel and D. E. LaLonde, "Science Success Strategies: An Interdisciplinary Course for Improving Science and Mathematics Education," *Journal of Chemical Education* 75 (1998): 1437; Donald J. Wink, Sharon Fetzer Gislason, Sheila D. McNicholas, Barbara J. Zusman, and Robert C. Mebane, "The MATCH Program: A Preparatory Chemistry and Intermediate Algebra Program," *Journal of Chemical Education* 77 (2000): 999–1000.

[28]Donald J. Wink, Sharon Fetzer Gislason, and Sheila D. McNicholas, *The Practice of Chemistry* (New York, NY: W. H. Freeman, 2004).

[29]L. P. Benezet, "The Teaching of Arithmetic I: The Story of an Experiment," *Journal of the National Education Association* 24 (1935): 241–244; L. P. Benezet, "The Teaching of Arithmetic II: The Story of an Experiment," *Journal of the National Education Association* 24 (1935): 301–303; L. P. Benezet, "The Teaching of Arithmetic III: The Story of an Experiment," *Journal of the National Education Association* 25 (1936): 7–8.

[30]Principal investigators at UNCW are Charles Ward and Jimmy Reeves. Available: http://aa.uncw.edu/numina/.

every few years, and this information eventually makes its way into the high school science curriculum. Many teachers believe that the high school science curriculum already has as much or more information in it as can be taught in the time available and that if new information is added to the science curriculum, some existing information must be deleted. Decisions about what information to delete to make room for new information will be wrenching because science is sequential—understanding new information heavily depends on understanding prior material. A likely better solution is to make the teaching of science more efficient. The science curriculum must be examined as a whole and concepts taught as they are needed. K–12 public education must be regarded as an integrated system, not as a system of individual grade levels, disciplines, or school levels.

Ninth grade physics, consequently, is a step in the right direction, with much potential benefit and few pedagogical problems. In one sense, moving physics to the 9th grade is simply correcting a mistake made a century ago, a mistake that was recognized as such at the time and unfortunately has become institutionalized. Anticipated difficulties to offering physics to 9th graders come from the need to turn the science program upside down, to re-educate many teachers in new techniques, to require teachers to write new lesson plans, and for guidance counselors and scheduling administrators to get used to the revised science sequence. Resistance by students and parents on the general grounds of "change is bad" is also likely. Obviously, considerable preparatory field work is required, such as explaining the benefits of the change to all stakeholders and, generally, selling the program. The curricula in the pilot programs should be taught by teachers who have bought into the concept and received specialized inservice education. Also recommended is district use of the Force Concept Inventory or other evaluations to assess both the magnitude of the difficulties at the beginning of the program and progress as it moves along. Some schools and school districts have successfully converted to the physics-chemistry-biology course sequence; San Diego, California, and Cambridge, Massachusetts are two notable examples. Although information concerning the conversions in Cambridge and San Diego apparently has not been published in the professional literature, program information is available on the Web sites of the respective school districts.[31]

Another possibility that should be considered is the substitution of the conceptual physics program for what is currently being taught in 7th and 8th grade science. This change certainly could be piloted without difficulty by using a teacher or teachers and students inter-

[31]Cambridge, MA, Public Schools Web site: http://www.cpsd.us/index.cfm; San Diego, CA, Public Schools Web site: http://www.sdcs.k12.ca.us/.

ested in seeing that the project succeeds. Success with these pilot projects could lead to physics being offered as an addition to the middle school program. When students who participated in the program get to high school, they could better fit into the existing science program and their progress could be observed to provide both data concerning the benefits of the program and to provide a positive example leading to buy-in to the program by other stakeholders.

Some method must be devised to assess elementary and middle school students' science learning. Specifically, we need to determine where and how students develop their deeply ingrained, incorrect worldview as uncovered by the extensive use of the Force Concept Inventory; the difficulty experienced in correcting this worldview indicates that it is acquired very early. The Force Concept Inventory may provide a means to achieve this purpose, although the test may have to be modified for use in upper-elementary school. If the situation requires correction, it can be corrected through the use of the kits developed by the National Academy of Sciences or the provision of knowledgeable, specialized elementary science teachers or by some other means. If the conceptual problem with the perception of physics is corrected in elementary school, the results will be long lasting. Money spent in this area can be regarded as an investment not just in benefits to students, but in terms of school resources that do not have to be expended later to undo the incorrect ideas held by students and to replace them with correct ideas.

In summary, 9th grade physics is a viable concept. Questions concerning implementation should not be of the "if" variety, but rather "how" and "when." Beginning with conceptual physics in the 7th or 8th grade using interactive learning techniques has an advantage: it can be easily piloted with a few students and teachers without turning the school schedule upside down. Success with this approach will provide a basis on which to build a stronger program. As confidence in the approach builds, the merit in offering 9th grade physics in high school will become apparent.

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