A Case for a Better High School Science Sequence in the 21st Century

By Fred R. Myers Jr.

Introduction

The theoretical breakthroughs and technological advances that have changed the face of science dramatically during this century were consequences of revolutionary concepts and of our vastly improved ability to peer into the previously elusive world of cells, molecules, atoms, and elementary particles. The effects have been far-reaching in the biological sciences as well as in the physical sciences, and have greatly impacted the lives of all of us.

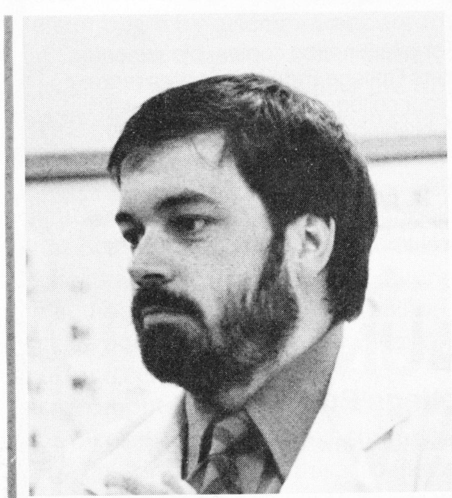
Secondary-school science programs in the United States have also advanced during this time period. However, it is my contention that science education in most high schools has not adequately paralleled our changing scientific and technological developments. One aspect of secondary science that has not sufficiently evolved, and thus, reduces the effectiveness of science education, is the biology–chemistry–physics (BI–CH–PH) sequence which dominates most schools. The origin of the sequence and the advantages of an inverted sequence physics–chemistry–biology (PH–CH–BI), make it clear that a shift in our secondary science programs is in order.

The Antiquated Logic of Biology First

The vast majority of American high schools offer the BI–CH–PH sequence in grades 10 through 12, or grades 9 through 11 for accelerated students.[1] A nationwide survey conducted in 1983 by Pfeiffenberger and Wheeler showed that as many as 98% of those students who take physics at the high school level take it during their junior or senior year.[2] It is rare to find a school willing to offer a standard high school physics course to 10th graders. The BI–CH–PH is, therefore, firmly entrenched.

How has it come to pass that we generally teach our courses in this sequence? The foundations of this sequence were laid in the early years of the 20th century, growing out of the nature of 19th century science.

Around the turn of the century, botany, zoology, and physiology were incorporated into what we now call biology, and were taught to promote better health practices and to provide some understanding of living things in relation to their environment.[3] Biology required large amounts of memorization and few, if any, clues as to the "why" and "how" of the functions of living organisms. Almost no mathematics was used.



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During the middle stages of the 20th century, however, the intricate relations between chemistry and biology became better understood, such as the nature and function of RNA and DNA. This was soon followed by a better appreciation of the relation of physics to biology. Today a typical high school biology course contains less memorization and significantly more consideration of the chemical nature of living things. Mastery of the biochemistry of Nature is essential to those desiring an understanding of Nature in today's world.

By the 1880s chemistry had become a widely offered high school course in the United States. Again, however, it involved only superficial understandings of chemical reactions, and the laboratory experience required little more than following a set of directions. The mathematics for such a course was limited to proportions and ratios.

Few significant changes occurred in high school chemistry until the late 1950s, after the launch of the Soviet Union's Sputnik. More theory was infused into the course content, including the concepts of bonding and energy. Thus, chemistry teachers are now building upon the physical concepts of force and energy to construct electron shell theory, and to explain chemical interactions, bonding, etc.

Physics was called "natural philosophy" when first introduced into high school curricula. In 1857 Massachusetts became the first state to require its public high schools to offer natural philosophy. Laboratory instruction quickly evolved and became an integral part of secondary-school physics offerings. The report of the Committee of Ten in 1892 elevated the standards of high school physics even further by demanding that it become more mathematically sophisticated.[4] In those days, of course, only a small fragment of the intimate relations among physics, chemistry, and biology was known. The breakthroughs and advances in the following decades were certainly not anticipated, at least not at the level of public education.

Thus, the stage was set in the early 1900s for the development of a science sequence for high schools. The selection was, at that time, clear cut:

1) Biology in the 10th grade because it relied mostly on memorization and required almost no mathematics.

2) Chemistry in the 11th grade because it relied heavily on memory and meticulous experimental procedures, and required modest amounts of mathematics.

3) Physics in the 12th grade because it demanded higher mathematical dexterity and relied heavily on analysis, problem solving, and critical thinking.

Advantages of a Science Sequence Inversion

There are several strong arguments for reversing the sequential order of the sciences to PH–CH–BI. These arguments fit into three fundamental categories that I shall call Logical Flow, Mathematical Reinforcement, and Population Awareness.

The Logical Flow argument is evident from what has already been presented. If physics is taken in the 10th grade, then the study of chemistry in the 11th grade could be done in greater depth and breadth; time would not have to be spent in the chemistry classroom dealing with the fundamentals of physics.

Analogous reasoning can be applied to biology in the 12th grade. With chemical competencies already a part of their academic arsenal, students would be better equipped to delve into the concepts underlying introductory biology. The pace could be faster, and the topics could be covered more adequately.

Another strong reason for teaching the sequence of PH–CH–BI is the Mathematical Reinforcement aspect. In most high schools algebra I is taught to the majority of students during their 9th grade year (to accelerated students in the 8th grade). Unfortunately, they are not called upon outside of math class to use many of these skills until their senior year if they enroll in a physics course. This two-or three-year time lag allows many of the skills to dissipate.

A solution to this would be to have physics taken in the 10th grade. Algebra I would then be followed in the very next year by a course which would reinforce students' mathematical skills through regular use. It would also serve to demonstrate some practical applications and uses of algebra. (Yes, physics can be taught using algebra I concepts without the more sophisticated mathematics of trigonometry. More about this later.) This steady use of algebra would help sharpen students' mathematical skills at a time when the nation is concerned with declining standardized test scores.

This brings us to the third fundamental category of support for PH–CH–BI sequence: Population Awareness. Since the implementation of more rigorous mathematical treatment of high school physics in the early 1900s, the percentage of students taking physics has declined dramatically. Nearly 20% of all high school students took physics at the turn of the century, while fewer than 5% do so today.[5] Clearly, the large majority of high school students in the U.S. do not experience a course in physics. This is alarming.

At what time in history was a general knowledge of physics most vital in appreciating and understanding the world's development and activity? The answer is TODAY! Physics and technological advances have pervaded our lives—from television to space travel to personal computers to nuclear power plants. It is important for the general population to understand the rudiments of physics so that they can better appreciate the advances and societal issues surrounding them. Without any understanding, unwise decisions and myths will flourish. Physics should be included in general education primarily "because it contributes so largely in educating children to be balanced individuals with an interest in the whole world around them."[6]

Revising the science sequence at the high school level would have considerable impact upon Population Awareness. First, it would expose the majority of students to the most fundamental of the sciences in the 10th grade. Secondly, more students would take more science because the "fear" of continuing in science would be greatly diminished.

Why Haven't We Inverted the Science Sequence?

We continue to present science in the BI–CH–PH order despite the strength of the foregoing arguments for reversing the order. The change has not occurred because some educators are pedagogically opposed to such a reversal and because of societal inertia.

Those opposed to the PH–CH–BI sequence generally contend that: 1) Tenth-grade students are not yet sufficiently mathematically sophisticated, i.e., they have not studied trigonometric functions and the quadratic equation; 2) Students in the 10th grade have not yet developed the abstract reasoning skills to digest all topics in physics; and 3) Significant amounts of time are not spent teaching chemistry in a biology class, nor physics in a chemistry class. Thus, the inversion would not save much time.

The first two arguments listed above lose their punch when it is realized that the physics course for 10th graders could not be the same course as physics for 12th graders. Clearly in a 10th grade physics course only mathematics through algebra I can be used, and clearly the topics must be treated in a more conceptual, concrete manner than they often are treated today. As I shall substantiate later, real physics can be taught to 10th graders...and with considerable success.

If textbooks are any indication of what goes on in high school classrooms, then considerable chemistry is taught in the biology classroom and some physics is taught in the chemistry classroom. Uri Haber-Schaim's study of sample textbooks clearly showed that terminology and topical treatment in leading biology texts contained surprisingly large amounts of chemistry. Similarly, although to a lesser extent, leading chemistry texts rely on concepts embedded in physics.[7] Physics textbooks, on the other hand, make little mention of chemistry or biology except for illustrative purposes.

Societal inertia may be the biggest obstacle to implementation of a PH–CH–BI sequence. Taxpayers, educators, administrators, and teachers are generally comfortable with the status quo and, therefore, resist major changes in curricula. On top of this, considerable time, effort, and money would have to be expended to adapt the courses and the teachers to the new student age level and to the students' altered backgrounds. Inherent in such a change would be massive training/retraining of teachers, particularly in the biology and physics areas. The already present shortage of qualified physics teachers appears to be the strongest argument against a sequence inversion. Clearly, additional incentives would be necessary. However, if the reversal ever takes place, the general quality of secondary science education would be significantly upgraded.

A Case in Point

The sequence inversion has been encouraged at a number of schools, including Choate Rosemary Hall, a relatively large, independent boarding school in Wallingford, CT. While this school has above-average-ability students, much of what we have experienced can be related to other secondary-school situations.

I have found Choate Rosemary Hall to be very receptive to progressive curriculum changes. In general, independent schools probably find it much easier to be flexible and to introduce innovative curricula. Public schools may have more constraints placed upon them.

For many years we had a program in place that allowed our very best (top 10–15%) of our 9th and 10th grade students to take physics. However, in the 1980s we have expanded this notion to include any of our 10th graders and "keenly interested" 9th graders. Given this history along with the science department recommending the PH–CH–BI sequence more strongly, the program is well established. See Table I for enrollment figures. For the benefit of students transferring into our school with some science background, and for other reasons, we still offer a sequence of BI–CH–PH. Therefore, physics can be taken at any of our grade levels, 9 through 12 (Table I.).

How well has the program worked? Many factors indicate that it has been successful.

Enrollments in the 9th and 10th grade physics program have nearly tripled in four years, while the enrollments in the junior/senior physics program have held fairly steady. Total physics enrollments have progressed as follows:

1979–80: 166
1980–81: 177
1981–82: 194
1982–83: 215
1983–84: 253
1984–85: 275
1985–86: 238

These are excellent numbers considering that each graduating class is about 300 in.number and that the total student population (grades 9–12) is less than 1000. In each of the last five years slightly more students have taken physics than biology, and the ratio of physics students to chemistry students has been about 8 to 5. These statistics are rare, indeed! During the same time, biology enrollments have increased, and chemistry enrollments have stayed relatively steady. Thus, total science enrollment has grown in four years by about 15%.

I feel that our 9th and 10th grade students are performing very well as physics students. The consensus of the physics instructors at Choate Rosemary Hall is that we are teaching them a legitimate quality high school course, and their testing performances have supported this conclusion. All students in the PH200 program were required to take the entire NSTA/AAPT National High School Physics Examination as their year-end exam in both 1984 and 1985. The 1984 group scored well above the national average. The 1985 group scored nearly as well as the 1984 group, but the official results have not yet been received. We also encouraged the top half of the PH200 students to take the 1985 SAT Achievement Test in Physics. Their overall average was approximately 650 (in fact, the 9th graders outscored the 10th graders!).

Conclusion

In recent decades scientific and technological advances have changed the nature and approach to high school biology and chemistry. It is evident that a PH–CH–BI sequence makes more sense and has many advantages over our present system.

Much attention has been focused upon the American educational system during the past few years. The public, as well as the government, is eager to find solutions to educational problems. If major changes are to be made, this seems to be an opportune time to enact them.☐

Table I. Enrollment figures at Choate Rosemary Hall [(PH–CH–BI) sequence].

Year	PH200	CH400	BI400	AP Phy.	AP Chem.
79–80	43	16	-	16	15
80–81	45	24	10	11	14
81–82	65	31	12	17	13
82–83	70	61	12	11	4
83–84	94	35	27	19	13
84–85	121	53	22	16	11
85–86	92	45	32	33	8

Notes regarding Choate Rosemary Hall courses:

PH200 is physics for 9th and 10th graders who have completed algebra I. CH400 is chemistry for those who have completed physics. BI400 is AP biology for those who have completed chemistry and have no previous biology course.

Each year the entire school has about 120 ninth graders and about 250 10th graders. About 20% of all PH200 students are 9th graders. Through the class of 1986, the science requirement was one full year of laboratory science. The requirement for the class of 1987 and thereafter has been altered to two years of science which must include one year of biological science and one year of a physical science.

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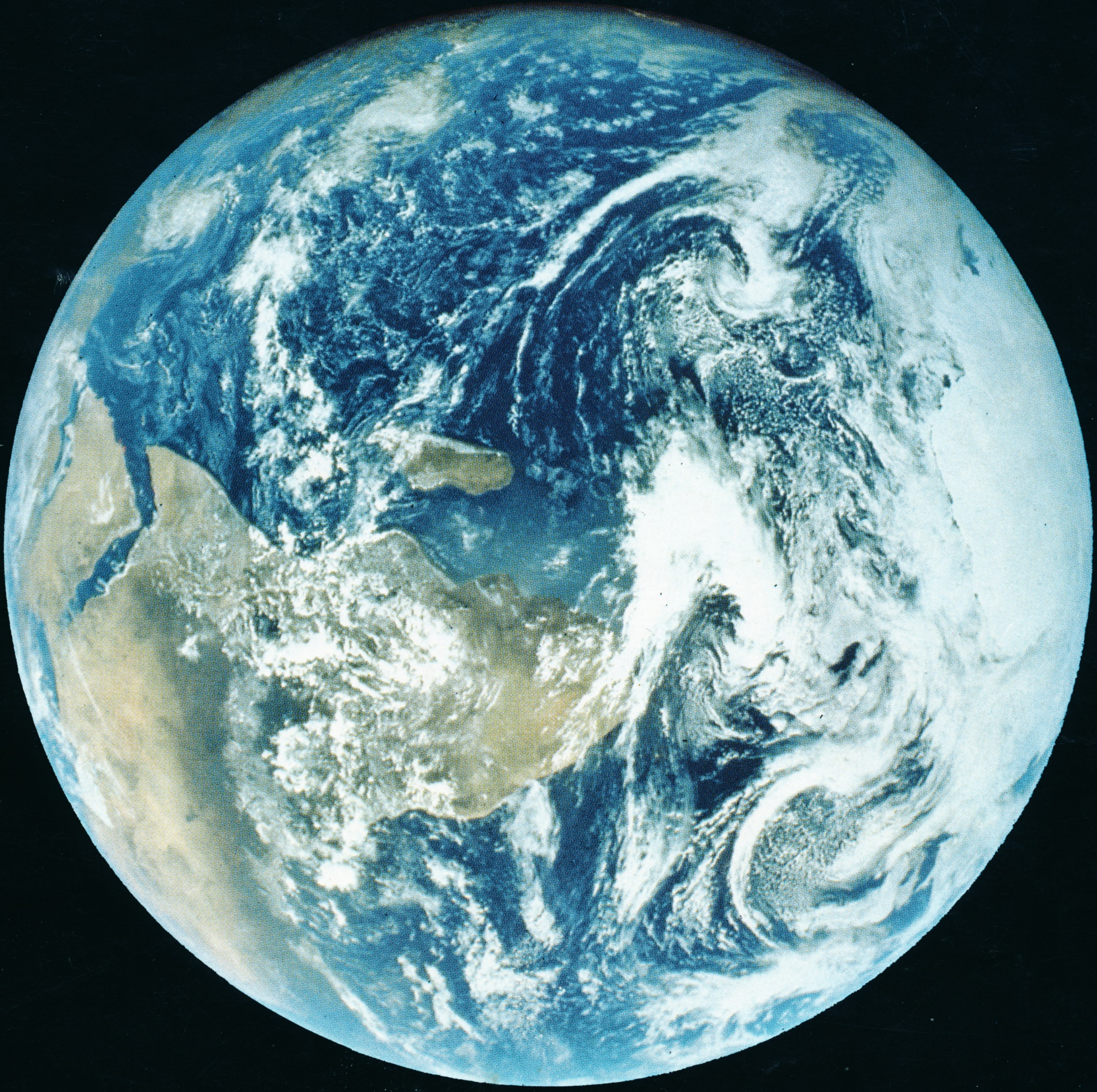

Does the Earth Rotate?