Inverting the High School Science Course Sequence:
An Improvement in Secondary School Science?

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In the past century, the world has evolved into a place in which a basic understanding of the sciences and their effect on our lives is becoming increasingly important. In this world, only those citizens armed with such an understanding are suitably prepared to participate in essential public decisions regarding critical issues as energy, the environment, national defense, AIDS, or genetic engineering. Equipped with an adequate understanding, people are not only better able to be a part of important public issues, they are also in a better position to make potentially life-saving personal decisions such as whether or not to wear a seat-belt when riding in a car, or to use a condom during sex. The bulk of the burden for providing such education rests with the schools and they should be organized in such a way as to optimize the process.

The world has changed dramatically in the last one hundred years as a direct result of our increased understanding of science and the interrelationships between the various disciplines of science. In spite of these changes, the overwhelming majority of American high schools cling to a science teaching sequence that originated about a century ago. That sequence, biology followed by chemistry followed by physics, is based on a rationale that may have been valid one hundred years ago but is inconsistent with the goal of producing the well-informed population necessary to make the best decisions with regard to national and world-wide policies on scientific and technology based issues. There is considerable evidence for the benefits of restructuring of the secondary science curriculum to invert this traditional order. Physics before chemistry before biology can be a more effective order for increasing student understanding of each of these major branches of science.

In an article discussing trends in the physics curriculum, Stewart Street (1967) discusses the evolution of physics curriculum in America. Physics, or natural philosophy as it was called until the last half of the nineteenth century, has been a part of secondary education almost from its beginning in this country. Records from early American "colleges" indicate that natural philosophy was the first science to appear in their curriculum. It should be noted that the term college had a different meaning at this time, and was more akin to what would today be called a high school. An 1837 report of the Regents of the University of the State of New York indicates that nearly every college in that state offered natural philosophy. In 1857 Massachusetts became the first state to require its public high schools to offer natural philosophy. The religious nature of many educational institutions had notable effect on the physics curriculum. As late at the second half of the nineteenth century, religious objectives for the teaching of natural philosophy were clearly stated. In an outline of studies for candidates of the ministry, Cotton Mather, the New England Puritan minister, gave the following advice: "What we call Natural Philosophy, is what I must encourage you to spend much more Time in the Study of. Do it, with continued Contemplations and agreeable Acknowledgements of the Infinite GOD, whose Perfections are display'd in His Works before you . . . And therefore, as thorough an Insight as you can get into the Principles of our Perpetual Dictator, the incomparable Sir Isaac Newton is what I mightly commend into you. Be sure, the Experimental Philosophy is that, in which alone your Mind be all established . . . ."

The first written record of Natural Philosophy being required for entrance into college was 1873 at Syracuse University. As colleges began to turn to high schools for increasing numbers of their candidates, they started to express concern about the inadequacies of high school physics programs. The Committee of Ten, activated by the National Education Association, advocated change in the physics curriculum of secondary schools. They recommended the appointment of a committee to consider uniformity in high school science programs. Charles W. Elliot, President of Harvard, chaired this committee, which met for the first time in November 1892. The following are a few of their recommendations regarding physics:

1. that the study of Chemistry should precede that of Physics in high school work;
2. that the study of physics be pursued the last year of the high school course;
3. that at least 200 hours be devoted to the study of Physics;
4. that there should be no difference in the treatment of physics for those going to college or to scientific school, and those going to neither;
5. that half of the time be devoted to laboratory work;
6. that in the instruction in Physics it should not be the aim of the student to make a so-called rediscovery of the laws of these sciences.

With the first two recommendations in this list, the tradition of teaching chemistry before physics, and teaching physics as the last course in the sequence, was firmly anchored.

It might be helpful to examine some of the potential reasons for recommending such a sequence. At the end of the nineteenth century, botany, zoology, and physiology were incorporated into what is presently called biology. Biology was taught, in part, to promote better health practices and to allow students to gain some understanding of living things in relation to their environment. Biology required large amounts of memorization but few clues as to the why and how of the functions of living organisms. The use of mathematics was almost non-existent. By the 1880's, chemistry was a widely available course in American high schools. It was, like biology, mostly a descriptive course. It involved only superficial understandings of chemical reactions, and the laboratory was akin to following a cookbook. The mathematics was limited to mostly ratios and proportions. Physics on the other hand, was easy to describe mathematically, and groups such as the Committee of Ten elevated the standards by demanding that it become more mathematically sophisticated. At the turn of the century, very little was known of the very close interrelationships between biology, chemistry and physics. The advances in each of the sciences that were to occur in the decades that followed were not anticipated.

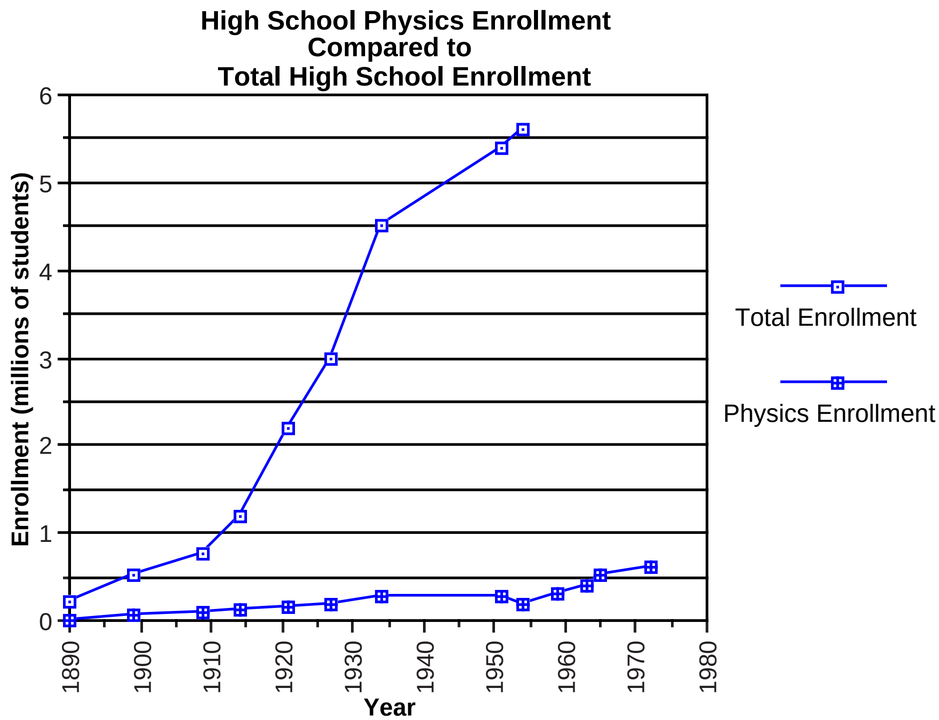
The selection of a high school science sequence was straight forward:

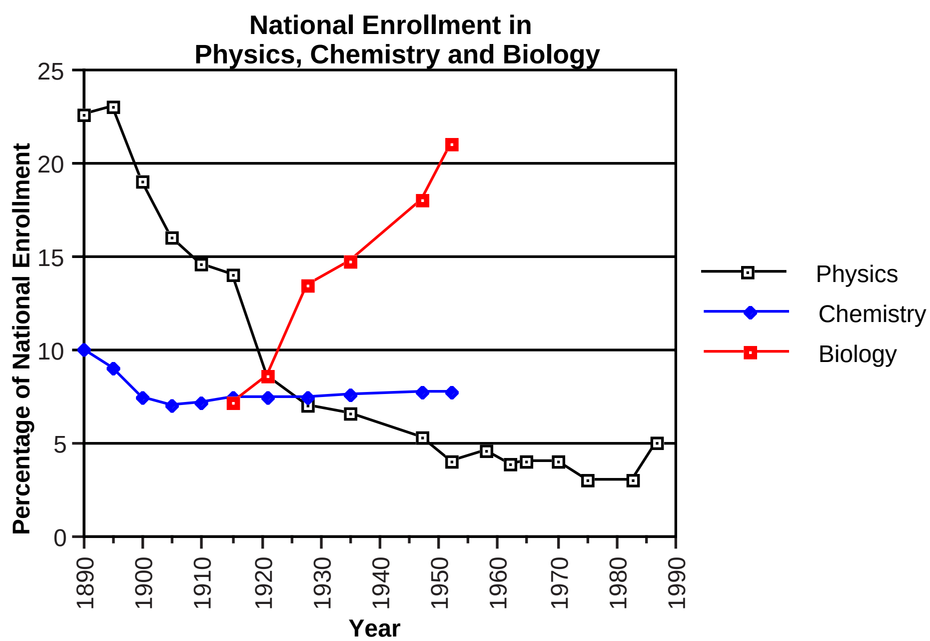
1. Biology at the outset of the sequence since it relied mostly on memorization and required almost no mathematics.
2. Chemistry next because it relied mostly on memory and detailed experimental procedures and required only modest amounts of mathematics.
3. Physics as the last course in the high school sequence because it required greater mathematical fluency and relied heavily on problem solving, analysis and critical thinking.

Given the state of the sciences at the turn of the century, this sequence may have made considerable sense. This sequence has continu-ed to be the overwhelming favorite of most high schools to this day. In a 1987 study done by the American Institute of Physics (Covalt & Neuschatz, 1988), it was found that fewer than 5% of the public schools in this country normally offer physics prior to chemistry. The rationale for following this sequence was essentially the same one used to struc-ture the sequence in the first place: Physics, as it is traditionally taught, requires more sophisticated mathematics than the other courses.

Leaving it to last allows students taking it to gain the broadest mathematics background prior to en-rolling. The effects of this reasoning have been devastating to the enrollment figures in high school physics.

The first graph that follows (Lindenfeld & Pallrand, 1985) shows the how the enrollment in high school physics has changed in relation to the total enrollment in American high schools. It is evident that it has failed to keep pace. The second graph shows the percentages of enrollment in the high school sciences in relation to one another. If one considers the percentage of students having taken physics prior to graduation from high school, the result is alarming. At the turn of the century nearly 90% of the students graduated having had a course in physics. As of 1987 only about 20% of American high school graduates have had a course in physics prior to graduation.





The ideas which led to the biology-chemistry-physics sequence continue to be espoused. The 1970 physics syllabus of the Regents of the state of New York stated the following in the introduction:

"The successful completion of physics usually requires slightly more maturity and understanding of mathematical concepts than does chemistry. It is, therefore, recommended that physics be placed at the top of the science sequence. While chemistry is not a prerequisite, if students are to take both chemistry and physics, normally they should be studied in that order." (cited by Haber-Schaim, 1984). It is interesting to note that the 1989 editions of the New York State Regents Physics Syllabus and the General Physics Syllabus (The University of the State of New York, 1989), which are the first revisions since the 1970 syllabus for each course, no longer contain such a statement. Could it be that the reasoning of a century ago is out of touch with the state of the sciences of today?

Increasingly since the 1940's, the intricate relationships between biology and chemistry have become more clearly understood. Modern biology is the most complex of the sciences. That understanding is based to a large degree on a better understanding of the chemistry and physics of living systems. It is difficult for a modern teacher of high school biology to make clear the ideas of biology in its current state without heavy dependence on the language and findings of chemistry and some reference to fundamental concepts in physics. Under the current sequence, students get that foundation in the two years following the completion of their biology course--if they happen to continue taking science courses. Likewise, modern chemistry courses depend heavily on an understanding of many basic physics concepts including such topics as atomic structure and energy. Those concepts are developed, of course, the following year in the physics course but only if the student happens to be the one in five that goes on to take physics.

To illustrate the illogic of the biology-chemistry-physics sequence, Uri Haber-Schaim (1984), one of the principal authors of the Physical Science Study Committee physics course, investigated the prerequisites in each of the other scientific disciplines in various science textbooks. He considered topic a prerequisite for a course if, for that course, the topic is used extensively without being developed in the textbook. In standard biology textbooks of the type typically used by freshmen and sophomores, he found an average of 23 chemistry prerequisites. In popular chemistry textbooks, he found an average of 31 physics prerequisites. However, in his examination of typical high school physics textbooks, he found no biology prerequisites and an average of only 2 chemistry prerequisites. How can we expect students to comprehend the subject matter of their high school courses in biology and chemistry if the concepts which underlie those subjects are not developed until after they have completed the courses?

Part of the persistence of the biology-chemistry-physics sequence can surely be attributed to the nature of the standard high school physics course. Most high school physics courses as taught to seniors at the end of the sequence do, in fact, cater to the most mathematically inclined of the student population. This same course could not be taught as the standard high school physics course if the inversion of the science sequence were to be realized. How much mathematics is really required in order to effectively teach physics? Most high school students take algebra during their freshman year in high school with the more advanced students often taking it in the eighth grade. Most topics in the introductory physics course can be handled with equations which are no more complex than $x = y/z$ (Swartz, 1971). The use of basic trigonometric functions is convenient but in no way essential to an elementary treatment of physics. Many physics teachers (Haber-Schaim, 1984) complain that even seniors have trouble applying mathematics to solve problems and evaluate experimental data. This observation might lead one to believe that present courses in geometry and algebra II do little for the senior level high school physics course. Perhaps, applying those mathematical concepts and skills in the intro-ductory physics course as (or shortly after) they are learned, with con- tinued use in science courses over several years, might be an effective way to help students gain a more permanent understanding of them.

Surveys indicate (Young, 1965) that there are several popular reasons students give for avoiding a course in high school physics. Three of the most popular reasons are listed below:

1. Students fear that grade point averages will suffer and college admission chances will be damaged.
2. Students have heard that the mathematical aspects of physics are treacherous.
3. Physics is difficult and students avoid it so as to have more time for other activities.

It is likely that in many schools such perceptions by students really do keep a large number of potential candidates for courses in high school physics from enrolling in those courses.

In 1986, the Academic Senates of the California Community Colleges, The California State University, and The University of California, issued a Statement on Physics Preparation Expected of Entering Freshman in the State of California. Portions of that statement (Barron, et al., 1988) follow:

> "The study of physics provides a systematic understanding of the fundamental laws that govern physical, chemical, biological, terrestrial and astronomical processes. Physics is the root science. The basic principles of physics are the foundation of most other sciences and of technological applications of science. Physics is also part of our culture and has had enormous impact on technological developments. Many issues of public concern, such as energy, nuclear power, national defense, pollution, and space exploration involve physical principles that require some understanding for informed discussion of the issues. Thus comprehending physics is important for a rational, enlightened citizenry to participate responsibly in decisions on public policy regarding complex technological issues.
>
> Physics is not just for physicists. In fact, few people who study the fundamentals of physics actually become physicists. Many enter related fields, such as engineering or other sciences, and many pursue nonscientific careers. For this reason, pre-college physics should be taught at a general level and should demonstrate the general principles of the science.
>
> Physics is an experimental science in that every statement of physical law is subject to verification and should be taught with this in mind. The relevance of physics to present and future technology should be made apparent.
>
> Mathematics: The physics course can be taught well with various levels of mathematical preparation. In fact, physics lends itself well to introducing students to the mathematical aspects of science. Physics is easy to describe mathematically, but it should not be inferred that physics can be easily learned mathematically. An overemphasis on mathematical analysis will disenfranchise many capable students from studying physics at the high school level. Ideally, a balance must be struck between the conceptual and mathematical aspects of physics--with neither predominating. Physics teachers should make reasonable adjustments in their presentations to ensure this balance and to keep the scientific level compatible with the mathematical preparation of their students."

This statement seems to be consistent with the notion of teaching physics as the first course in the high school science sequence.

The importance of offering physics to more than an elite group of mathematically gifted students is not a new idea. In 1909, John Dewey published a paper (Moyer, 1982) entitled "The Purpose and Organization of Physics Teaching in Secondary Schools." In this paper Dewey stresses that high school physics instruction should, above all else, serve society. A few quotes from Dewey's paper follow: "The importance of the social applications of physical science in modern life should be borne constantly in mind both in selecting and in presenting subject matter. . . .Contemporary civilization rests so largely upon applied science that no one can really understand it who does not grasp something of the scientific methods and results that underlie it; on the other hand, a consideration of scientific resources and achievements from the standpoint of their application to the control of industry, transportation, communication, not only increases the future social efficiency of those instructed, but augments the immediate vital appeal and interest of the subject. . . . In secondary education, their value (the teaching of scientific methods) and hence their limits are fixed by the extent to which they react to create and develop logical attitudes and habits of mind. . . . A new type of mind is gradually developing under the influence of scientific methods; the physics teacher should do what in him lies to hasten the extension and the supremacy of this type of mind." Dewey was obviously well aware of the high school physics course as fertile ground for the development of critical thinking skills in addition to preparing a well informed public. Dewey's ideas are consistent with the idea of physics for every student, not just for the elite few whose mathematical sophistication would permit them to participate in a typical high school physics course.

If one agrees that physics is a course that should be taken by the majority if not all high school students, then several questions remain as to its proper placement in the curriculum. Can effective courses be taught which will allow students to grasp the important concepts of physics without the mathematical sophistication required by the typical course? Does physics, as the foundation of the other sciences, belong at the bottom of the pyramid or in its current place at the top? Can freshmen or sophomores handle a course in physics? Many people, including some high school physics teachers, would argue that physics for the masses and especially at the freshman or sophomore level is an unreasonable goal. The facts are, however, that successful courses in physics <u>have</u> been developed which are appropriate for most if not all students. That good physics <u>can</u> be taught without relying upon sophisticated mathematics beyond the capability of students. That there are several schools that have successfully used the physics-chemistry-biology sequence, with marked improvement in achievement in those subjects.

In 1987, Addison-Wesley Publishing Company began publishing a textbook and materials for a course in physics appropriate for virtually all students. This course, <u>Conceptual Physics: A High School Physics Program</u> was developed Paul Hewitt. Hewitt (1987) considered the broad spectrum of the student population, including those who would benefit from but usually don't take a course in physics, when he designed the course. Hewitt's text is written at a ninth grade reading level. When introducing students to the text, Hewitt states "physics is treated conceptually rather than mathematically. Physics concepts are in English, with equations as 'guides to thinking' rather than recipes for algebraic problem solving. This means you'll really be able to comprehend the physics you study. Then if you take a follow-up course in physics, you'll get algebraic problem solving. So comprehension now, and if computation follows later, it will be with understanding!" Since its introduction in 1987, Hewitt's text has become among the best-selling high school physics programs in the country.

Several articles have appeared in science education journals over the past twenty years that describe successful programs which offer physics to students long before the senior year in high school and which demonstrate success with the physics-chemistry-biology sequence. A sampling of the titles of some of these articles includes <u>Physics in the Seventh Grade</u> (Grant, 1974), <u>Quantitative Physical Science in the Junior High School</u> (Githens, 1970), <u>Take Physics to Ninth Graders with Budget Savers</u> (Carpenter, 1974), <u>Freshman Physics</u> (Hickman, 1990), <u>Physics in the Tenth Grade</u> (Sousanis, 1971), <u>Physics and the High School Sophomore</u> (Hamilton, 1970), and <u>Physics Before Chemistry</u> (Bolton, 1987). The results described by teachers at schools that have tried the physics-chemistry-biology sequence have been impressive.

In an experiment with the inverted sequence (Palombi, 1971) which started over twenty years ago in Rome, New York, students who voluntarily undertook this sequence showed no decline in physics scores when compared with those undergoing the traditional sequence. They showed a dramatic improvement in chemistry and biology scores. The sequence began in the sophomore year with students taking the same "Regents physics course" as was taken by senior students from the same teacher. At the end of the course both groups were given the New York State Regents examination in physics. The average earned by the sophomores was 81.4% compared to the seniors average of 81.8%. That group was then uniformly distributed among the school's chemistry classes for the following year. The group which had taken physics as sophomores scored an average 93.3% on the Regents chemistry exam, compared to a schoolwide average of 79.5% and a statewide average of 78.9% on the same exam. Finally, as seniors, the group was scattered among the schools biology classes. The average score by this group on the Regents biology exam was 92.0% whereas the schoolwide average was 79.4% and the statewide average was 75.1%. It is interesting to note that the second group of volunteer sophomores to undergo the inverted sequence averaged 80.7% on the Regents physics exam compared to only 75.8% for the seniors. Some typical comments about the inverted sequence by students who followed it included the following: "By studying physics before chemistry or biology, I gained an understanding in scientific procedure and logical reasoning." "I think that biology could be better taught and understood if my sequence was required." "I think that with the understanding of the concepts of physics and chemistry, a student can more efficiently understand biology by incorporating these concepts in his study of biology." The students and teachers who participated in this experiment concluded that the sequence had definite merit.

In a recent similar experiment at a school in Connecticut (Myers, 1987), physics enrollment was seen to nearly double while chemistry enrollment remained fairly steady and biology enrollment increased. In other words, having students take physics at the beginning of the sequence did not have the anticipated effect of decreasing biology enrollment. Overall enrollment in the sciences was seen to increase by about 15% after the installment of the inverted sequence. This school noticed similar improvements in achievement test scores to those noted in Rome, New York. All students in the course which was part of the physics-chemistry-biology sequence were required to take the entire NSTA/AAPT National High School Physics Examination as their year end final examination. This group of freshmen and sophomores scored well above the national average on this examination.

The science department at Cold Spring Harbor High School in New York offered the inverted sequence to students beginning the freshman year (Hickman, 1990). The freshman physics course is taught using Hewitt's Conceptual Physics program. Once again, the performance of the students involved in the inverted sequence on the Regents physics examination was consistently better than the juniors and seniors taking the same course. Paul Hickman (1990), the author of the article and a physics teacher at the high school outlines the following advantages and disadvantages of teaching physics to ninth graders:

Advantages

- Although students have had less exposure to mathematics courses than seniors, the algebra that they need most is still fresh in their minds
- Students are enthusiastic and highly motivated to succeed.
- Most students who take physics first go on to complete the science sequence.
- Students feel special after completing "the hardest course in the school" as ninth graders.
- Math teachers find increased interest since the students are using the math concepts daily.
- Enrollment in the senior course increases, and fear about taking this "difficult" course subsides, especially among girls.
- Students perform at least as well and usually better than the juniors/seniors.
- Community interest in physics increases, especially when the change is first proposed.
- Many schools might now have the opportunity to offer AP physics, AP chemistry, a research course, or science electives since students will now have time in their senior schedules.
- Students have an easier time in chemistry.
- AP biology can be taught as the first biology course if physics and chemistry have been studied.

Disadvantages

- Shortages of qualified physics teachers.
- Opposition on the part of parents, administration, and teachers: why change from the proven, "traditional" biology-chemistry-physics sequence?
- Ninth graders are more active, noisier, and less coordinated.
- Measurement and estimation skill are almost nonexistent.
- Trigonometry has not been studied.
- Abstract ideas are more difficult to teach.
- Many ninth graders have memorized their way through every other course and find that this strategy does not work well in physics.
- Additional "problems" for the guidance department.
- Problems of transition from junior high to senior high level course.
- Lack of "problem-solving" and "test-taking" skills.

Hickman (1990) believes that the advantages he cites far outweigh the disadvantages. Others in his school share this sentiment.
Correspondence with teachers from other schools in New York and across the nation that have tried the inverted sequence have revealed many rewards as well as common problems. He says that all of those that he has talked to who have tried the inverted sequence agree that it can work!

The shortage of qualified physics teachers which Hickman (1990) describes as a disadvantage is no small matter. There is <u>already</u> a significant shortage of physics teachers and there are relatively few new ones being trained. Many existing physics teachers are nearing the age of retirement. It has been said that the average age of high school physics teachers is increasing at the rate of one year per year. To make matters worse, it is in many ways more difficult to teach physics "conceptually" because illustrating important physics concepts without hiding behind a shield of mathematics requires a deeper understanding of the concepts on the part of the instructor. Most physics teachers learned physics in the standard mathematical manner and are unfamiliar with ways of developing the concepts without the aid of lots of math. Since one of the major goals of an inverted sequence is to significantly increase enrollment beyond the current dismal statistics, this shortage of physics teachers will be compounded even further. Additionally, the enhanced background of the students entering biology classes with physics and chemistry under their belts would require many biology teachers to drastically alter the biology courses that they teach. They would not only be able to but would be compelled to offer a course which strayed from the typical descriptive approach and open up for students the real world of modern biology. Many current biology teachers would require substantial retraining to be able to competently teach such a course.

If as a nation, we are truly interested in a better educated public, then one place to start would be with the upgrading of the teaching of science in our schools. Physics, as the foundation of all of the sciences, is a course that is an essential basis to the understanding of any science. It is vital in appreciating and understanding the scientific and technological issues that pervade our lives. We simply cannot continue to be satisfied with only 20% of the population having sufficient understanding of science-based public issues to make intelligent choices on those issues. We must come as close to 100% as possible. The introduction of a more conceptual and less mathematical physics course as the base of a new physics-biology-chemistry sequence could favorably affect that goal. This sequence would expose the majority of students to the most fundamental of the sciences in the ninth or tenth grade. This would not only drastically increase enrollment in physics but would result in a greater number of students taking more science because the "fear" of continuing in science would be significantly diminished. The shortage of qualified physics teachers seems to be the strongest argument against this sequence. It is apparent, however, that the physics-chemistry-biology sequence makes great sense and offers substantial advantages over our present system. With the increased attention that the American education system has received in recent years and the eagerness of the public to find solutions to educational problems, the time to take a serious look at this sequence is <u>now</u>. If this sequence reversal ever does become the new "norm", the general quality of secondary science education will be greatly enhanced.

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