A movement has slowly been sweeping the nation involving a reversal of the science sequence in high school from biology, chemistry, physics (BCP) to physics, chemistry, biology (PCB). Such a change would require the complete renovation of our high school science programs, retraining of high school teachers, revamping of the credential programs at the universities, and (under NCLB guidelines) either the re-education of biology teachers to teach physics or the termination of their employment and hiring of physics teachers (who are already scarce). The cause of such a heavy burden must be a cause backed by many years of data. Unfortunately, Spencer Pasero summarized it well when he said, “Physics-First schools are not quantitatively documenting the degree of their success” (Pasero, 2001). Also, Pattanayak says, “Interviewees had numerous anecdotes to support their efforts, but most of their schools had collected no numerical data for evaluative purposes" (2003).

This study will analyze data regarding Physics-First. Being from California, the author will focus on that state for several reasons. First, content tests are given to every 9th, 10th, and 11th grade student who takes a science course. The results of these tests can be broken down by district or school via the Internet. Second, one of the largest districts in the state, San Diego Unified, has adopted the Physics-First approach.* This offers a lot of Physics-First data to be analyzed. Third, in the reporting of the test scores, each school is compared to 100 schools demographically, socially, and ethnically similar as identified by the state. This gives the opportunity to compare schools using the BCP path and the PCB path at demographically similar schools.

*Since the writing of this paper, San Diego Unified has reversed its stance on physics first and has now made it optional. After the science Instruction Materials adoption cycle, more than half of the high schools chose to return to the BCP sequence.

To establish criteria to analyze, one must be familiar with the arguments normally used to advocate Physics-First. One common argument is that Biology is becoming significantly more advanced and the need for chemistry and physics before biology is greater (Allen, 2004). Another is that all students should be exposed to physics (AAPT, 2002). Yet another is that this introduction to physics will increase the enrollment in more advanced physics classes such as college preparatory physics or Advanced Placement (AAPT, 2002). Another is that physics is conceptually the easiest of the sciences and should come first. This is usually countered by the fact that it is the most mathematically complicated and should come last, thus creating a dilemma. Another argument is that physics first will improve performance in both Biology and higher-level Physics classes. Still another argument is that students learn the math that they need to be successful in Physics while in middle school (cite New York article). Another reason given is that teachers prefer this sequence.

The argument that Biology is becoming significantly more advanced does not seem to hold water. In California, teachers are required to teach the California Science Content Standards (CDE, 1998). These standards were adopted in 1998 and have changed very little since then. They have been adopted until the year 2011. If the Biology curriculum is changing, from where are these changes coming? To take the task to point, one can compare the relative sophistication of the content standards via Bloom's Taxonomy. One may assume that the subject with the greatest number of standards on the lowest level of the taxonomy is the least difficult for students to learn. Any standard that involved simply knowing or recalling a fact was placed at the "know" level. Standards which involved understanding, solving, explaining, using, reasoning, constructing, relating, comparing, applying, predicting, or identifying were put into the higher category (Figure 1). Clearly the results show increasing depth as one traverses the

BCP pathway. The Biology standards have 54 in the “Know” realm and the indicated number of each of the following: predicting (3), using (2), applying (2), distinguishing (1), solving (1), and differences (1). That’s over 540% more standards at the lowest level than all of the others combined. Chemistry has 41 standards in the “Know” realm and the indicated number of each of the following: calculate/solve (7), use (7), relate (3), identify (3), apply (3), describe (3), draw (1), predict (1), determine (1), convert (1), and relationship (1). That is 33% more in the lowest level than the others combined. The Physics standards include 24 in the “Know” realm and the following: solve/calculate (17), apply (2), identify (2), predict (1) and determine (1). That is 4% more in the lowest level than in the rest combined.

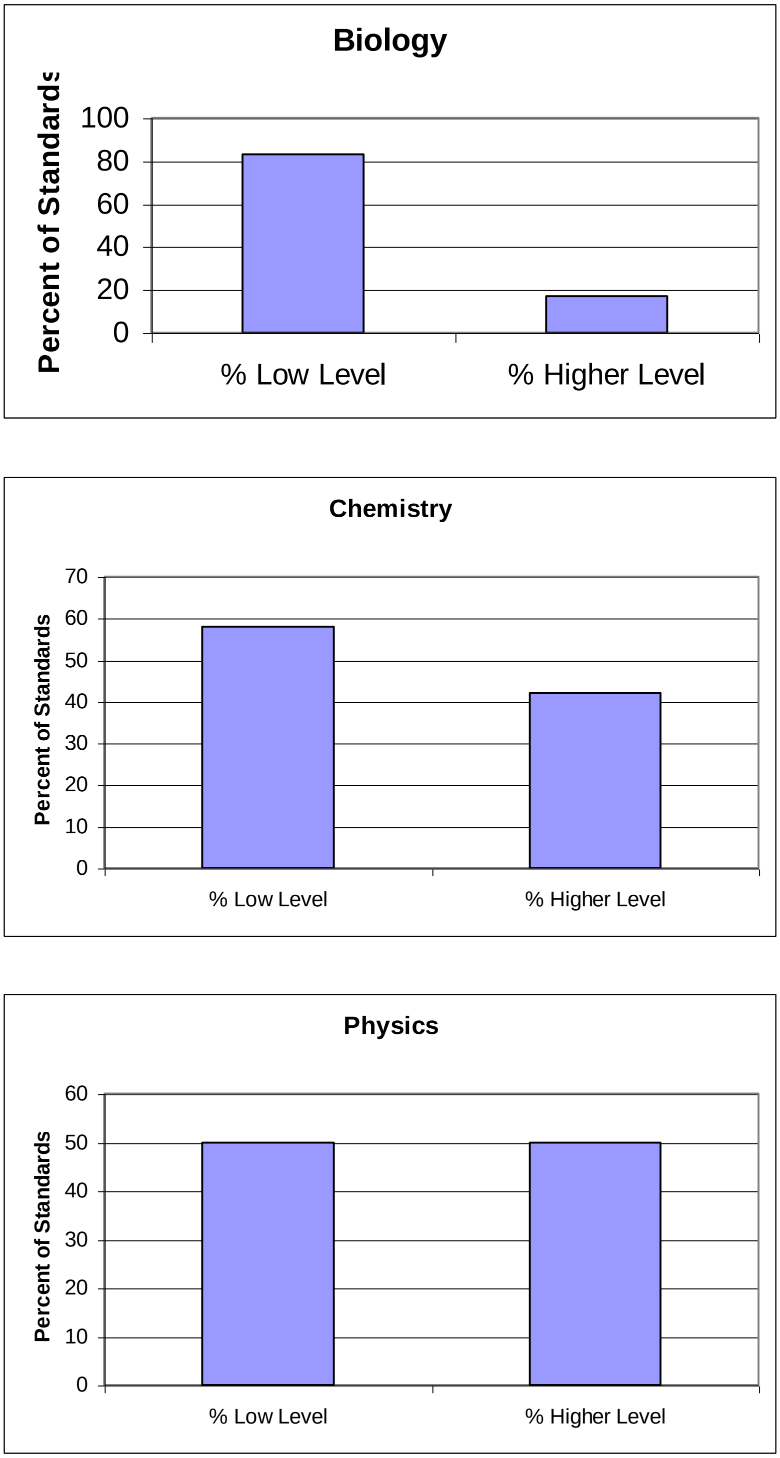


Figure 1. Percentage of content standards on the lowest level of Bloom's Taxonomy

To see if physics first improves performance in other science classes, the lists of 100 similar schools were used. Charter schools, private schools, and classes with less than 15 students were all thrown out. The author's former school was used first, but this did not generate enough data as there were only five schools on the list teaching physics first, so the other high school in the author's district (which was teaching physics first at the time but has discontinued the practice) was added. Percentages were rounded to the nearest 5%.

Figure 2 shows how BCP and PCB schools performed on the Physics portion of California's CST Physics test. It is abundantly clear that BCP schools outperformed PCB schools by a large margin. It can be argued that BCP schools educate only the best of their students in physics, but it can be seen that 12 out of 20 BCP schools had 0-2.4% proficiency on the exam. Even those students who would have been proficient in a BCP program tested as not proficient on the exam in the 9th grade. Some would argue that the test is biased towards mathematical calculations, but the California test does not even allow the use of calculators. Any calculations required must be simple. Also, the test is based upon the Science Content Standards and any high school physics class should cover those standards. Whether or not those standards are appropriate is not within the realm of this study and is highly dependent upon one's opinion. The standards were developed by a highly qualified committee and were open for public comment before adoption. It is the author's feeling that any course that does not prepare students to do well on these standards is not a proper course. Yes, there is a lot more to learning something well than just taking a low-level multiple choice test, but one could make an argument that if a student cannot pass a simple multiple choice test, then those other, more advanced forms of demonstrating knowledge are impossible.

Figure 3 shows the performance of BCP and PCB schools on the biology portion of the examination. At most California high schools, all students take either Biology or Life Science and then take the CST Biology exam because most graduation requirements as well as the requirements to attend a state university require a life science course. There is no argument possible that more students are tested at one type of school (BCP vs. PCB) over the other. It is clear from the graph that there is no correlation between when one takes physics and how one does on the biology test. The highest percentage was at a PCB school, but 8 out of the top 10 scores were at BCP schools. At the lower end, the scores are well mixed.

Figure 2 and Figure 3 show that there is a strong correlation between when physics is taken and the percentage of students being proficient in physics. Percentages were higher when students waited to take physics. Recall that there was no clear correlation between when one takes physics and how one does on the biology examination and a strong positive correlation with physics success. Both of these arguments appear to be false according to this data.

Many teachers argue that those who teach physics first like it better. Since the switch involves biology and physics teachers, their opinions may be biased. Seeking chemistry teachers' opinion would be less biased. The American Chemical Society did a poll of chemistry teachers asking, "Which high school science topic should be taught first" (chemistry.org, 2005). Of those contributing to the poll, 43% (17,500) thought that biology should be taught first and only 23% (9153) thought that physics should be taught first.

It is not enough, in my opinion, to say that a program does not work without suggesting what might be done in its place. Many physics-first activists suggest that students are academically capable of taking physics as early as the 8th grade. Numerous studies have shown that Active Engagement strategies such as Modeling, Inquiry, and Discovery are very effective in promoting long-term retention and science process skills. Inquiry is strongly recommended in the National Science Education Standards and International Baccalaureate program. The physics first data in this study show that those strategies alone are not enough to make freshmen successful in physics.

Biology teachers contend that they spend a lot of time teaching pH, light, colors, chemical reactions, solubility, concentration, gases, atomic structure, conservation of mass, conservation of energy, and the periodic table (cite New York article). These are mostly chemistry concepts with a few physics concepts sprinkled in. There is no need for Ohm's Law, conservation of momentum, projectile motion, series and parallel resistors, nuclear physics or many of the other topics taught in a standard physics course.

San Diego City Schools missed a very important point when they switched to physics first; every student in California already takes Physics and Chemistry before Biology in the BCP model. California requires students to take Physical Science in the 8th grade. This is one semester of chemistry and one semester of physics. If San Diego had realized this, the solution to the problem would have been crystal clear. The curriculum in the 8th grade Physical Science classes needs to be adjusted so as to focus on those topics listed above that will support Biology teachers in the 9th grade. Most of the topics are already on the list of standards so only small changes would have to be made. To ensure that students remember the material in the 9th grade, Active Engagement strategies should be utilized.

The California Science Content Standards should be modified slightly to expressly encourage Inquiry and to use 7th grade Life Science and 8th grade Physical Science to prepare students for 9th grade Biology. In high school, students normally either take Biology, Chemistry, Physics or Life Science, Earth Science, Physical Science. At the worst, every student would be getting two semesters of physics (PS in middle school and PS in high school). Alternatively, they would be getting three semesters (PS in 8th grade and Physics in 11th grade). This would still leave the senior year available to take another elective science class or an AP Physics class if the student chooses. This approach also resembles the spiral approach to education practiced in Japan and other countries with higher TIMMS scores than the US (reference). This model solves the problem of physics for all as well.

In this model, 7th grade Life Science students would learn basic cell structure (already included), plants and animals (spread throughout elementary school), basic genetics (already included), evolution (already included), and basic microscopy (already included). In 8th grade Physical Science, students would learn those Chemistry and Physics topics listed above. In California, 8th graders study motion, forces, structure of matter, chemical reactions, biochemistry, the Periodic Table, and density and buoyancy as well as Investigation and Experimentation standards. As one can see, all of the topics needed to prepare for biology are already taught in the 7th and 8th grade.

What will need to be done?

The best part about this program is that it does not require any major shifts in personnel. First, K-12 science teachers will need to be trained in Inquiry techniques. This change is also recommended if Physics is taught in the 9th grade so it is common to both plans. This change will allow Biology teachers to count on the fact that they will not have to spend up to 6 weeks reviewing science concepts and will allow them more time to use Inquiry strategies as well. Other states will have to evaluate their programs and potentially modify existing middle school content standards to better reflect a “preparation for high school Biology” strategy. In California, very few changes would need to be made to make this happen.

Credential programs and teacher education programs will need to be changed so that future teachers will be prepared for this practice upon certification. Inquiry strategies and teaching of the standards should be the focus. County offices and district offices should prepare existing teachers for the shift to inquiry strategies. Books, websites, summer programs, and grants already exist to promote inquiry instruction. University of the Pacific and the San Joaquin Office of Education teamed up on an NSF GK-12 grant to train teachers in inquiry and then have graduate students visit the classrooms to help them implement the strategies. Arizona State University offers a 1-week summer program for teachers to learn about modeling physics. Orange County Department of Education wrote a CAMSP grant to train 4^{th} and 5^{th} grade teachers in Inquiry.

If creating graduates who are scientifically literate is the goal of education, then a spiraling curriculum based on inquiry strategies is the research-based solution. It takes into effect both the "basic physics first" in middle school and "advanced physics" last practices. A 3-year graduation requirement in science would go a long way towards solving the "physics for all" problem.

AAPT. (2002). AAPT statement on Physics-First. Retrieved June 26, 2005 from http://www.aapt.org/Policy/physicsfirst.cfm

Pattanayak, V. (2003). Physics first in science education reform. Journal of Young Investigators. Retrieved June 26, 2005 from http://www.jyi.org/volumes/volume6/issue7/features/pattanayak.html

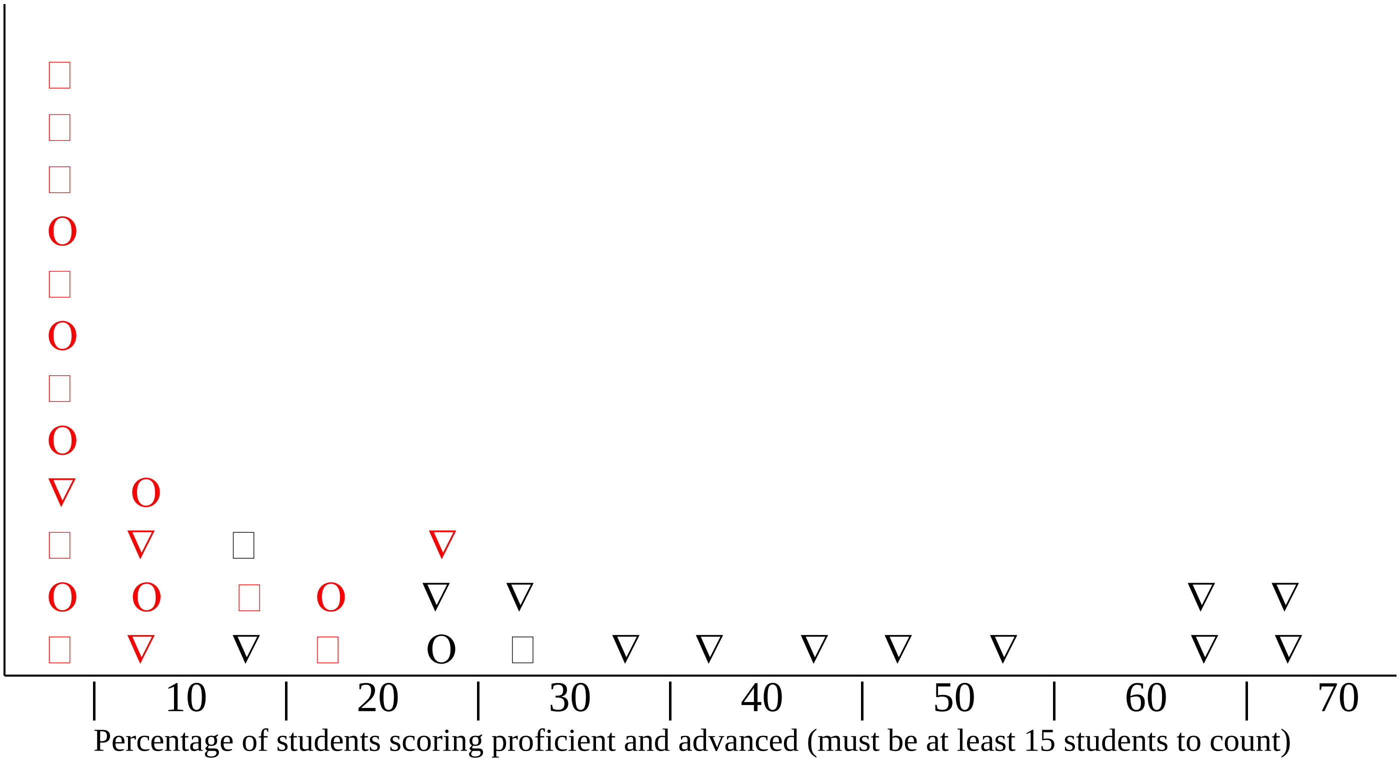
Allen, R. (2004). Shaking up science. Curriculum Update. Retrieved June 25, 2005 from http://www.ascd.org/affiliates/articles/cu2004summer_allen.html

AAPT. (2002). AAPT statement on Physics-First. Retrieved June 26, 2005 from http://www.aapt.org/Policy/physicsfirst.cfm

Pattanayak, V. (2003). Physics first in science education reform. Journal of Young Investigators. Retrieved June 26, 2005 from http://www.jyi.org/volumes/volume6/issue7/features/pattanayak.html

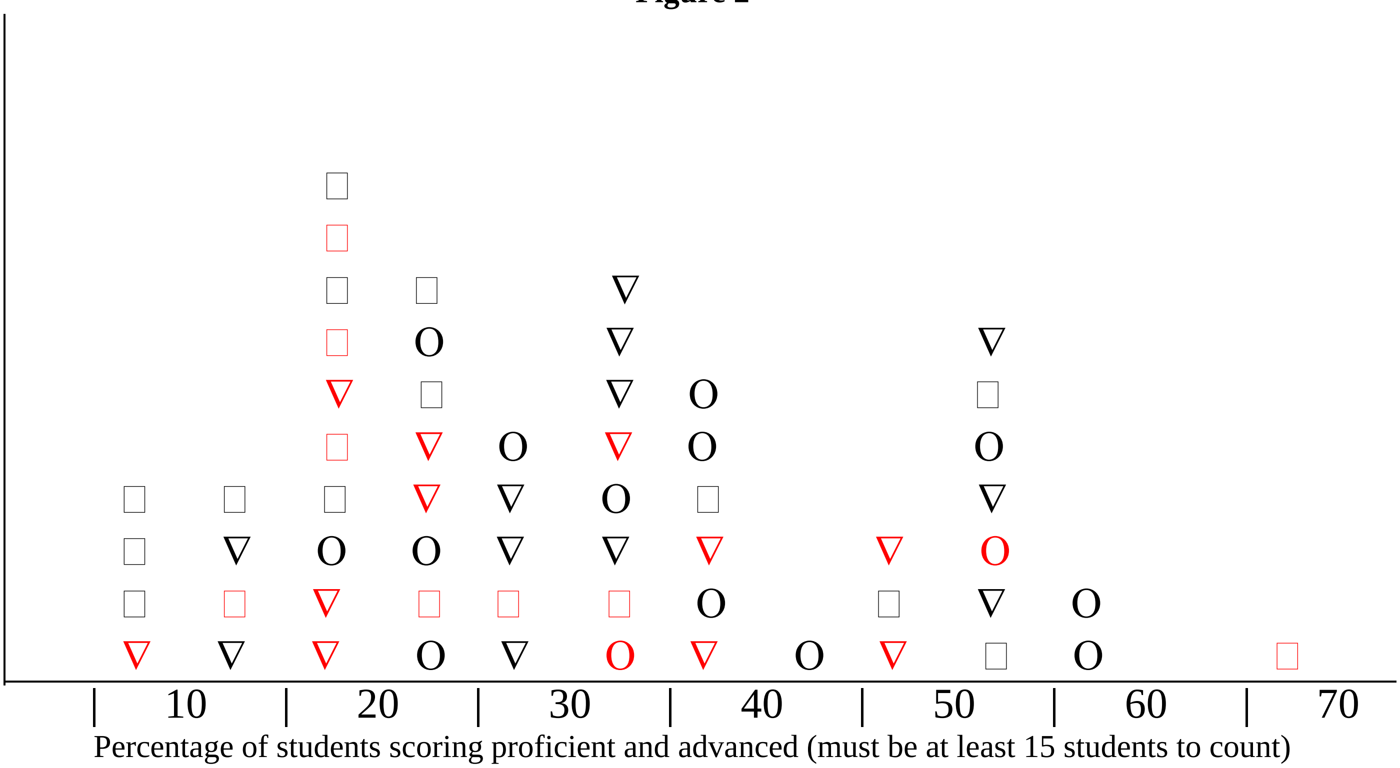
Allen, R. (2004). Shaking up science. Curriculum Update. Retrieved June 25, 2005 from http://www.ascd.org/affiliates/articles/cu2004summer_allen.html

BCP= O 9^{th} □ 10^{th} ∇ 11^{th}
PCB= O 9^{th} □ 10^{th} ∇ 11^{th}



Physics

Figure 2



Biology

Figure 3