

**Current Research on High School
Science Course Sequencing**

Joy Dike

Introduction

According to the National Science Education Standards, “the program of study in science for all students should be developmentally appropriate, interesting, and relevant to the students’ lives” (National Research Council [NRC], 1996, p. 214). The purpose of this paper is to look at and understand the current research on high school science course sequencing. The term “sequence”, when used in this paper, will refer to the particular ordering of courses, such as biology, chemistry, and then physics.

Creating educational change is a lengthy and involved process, which should not merely be a remodel of an old curriculum, especially if the old curriculum is ineffective. If the work has been put into deciding that change is necessary and do-able, the planning process should begin from scratch with a philosophy of education and pedagogy. Quick and superficial changes that are assessed too quickly may do more harm than benefit to the students and teachers involved.

The sequence of science courses at the high school level has been considered at least as far back as 1894 in the Report of the Committee of Ten on Secondary School Studies (National Educational Association [NEA], 1894). Much more recently, the debate has taken on new life with the advent of Project ARISE (American Renaissance on Science Education), a project sponsored by the Fermi National Accelerator Laboratory in Illinois and partially funded by the U.S. Department of Energy.

According to research, the courses taken in high school are tangible experiences with real consequences for students’ lives during and beyond high school. The science courses a student takes can exert a “strong and statistically significant influence” on achievement in science (Schneider, Swanson, & Reigle-Crumb, 1997, p. 37). This is

significant information for students, parents, teachers, and administrators alike. In fact, Schneider et al. (1997) found that the science courses taken were a better predictor of test scores and test score gains than different curricular tracks, meaning that the ability level of the class was not as important as the progression along a sequence of science courses. The same study also found that the courses taken in high school were more predictive of college entrance than family background effects or the type of school the students attend (e.g. public, private, or religious). Although some may disagree with the importance Schneider et al. put on courses taken and college entrance, the fact is that the sequence of courses in high school is an important consideration for all parties involved in the education of America's youth.

Most states in the United States require only two or three science courses in high school, rather than a coherent sequence of science courses. The most frequently taken course is descriptive biology; only half of all students complete chemistry; and only one-fifth of all students complete physics (Lederman, 1998). This outlook is even bleaker for girls, with only 7% of girls enrolling in physics courses (Bardeen, 2002). The traditional series of science courses, biology, chemistry, and physics, are mostly textbook-driven courses that are treated as unrelated and disconnected disciplines. The traditional courses are often taught as a collection of facts and principles to be memorized, where a genuine understanding of one discipline (i.e., course) is not necessary for progression on to the next course in the series.

The Committee of Ten on Secondary School Studies

The Report of the Committee of Ten on Secondary School Studies has some similarities to the current National Science Education Standards (hereafter referred to as

the *Standards*). Both are based on the idea that educational standards should be somewhat consistent throughout the nation, with equal opportunities and education available to all students. (Of course the term “all students” did not, in 1894, mean the same thing that it means in today’s society.) The Committee of Ten was the result of the National Council of Education, and the *Standards* are the results of National Education Goals Panel, the National Science Foundation, and other governmental organizations. Both were written by representatives from around the nation, which allowed for input from various states and regions.

Both the Committee of Ten’s report and the *Standards* are recommendations for implementation, with a goal of having “uniformity in school programmes” (NEA, 1894, p. 3), or a “national vision” (NRC, 1996, p. 12) for education. In fact, the NRC says, referring to the document as purely suggestions, “A hallmark of American education is local control, where boards of education and teachers make decisions about what students will learn. National standards present criteria by which judgments can be made by state and local school personnel and communities, helping them to decide which curriculum, staff development activity, or assessment program is appropriate” (p. 12). The Committee of Ten say something similar when they write, “the selection and order of science subjects might be varied considerably to suit the needs or circumstances of different schools” (NEA, 1894, p. 49).

The goal of the Committee of Ten’s report was to prepare students for the “duties of life” (1894, p. 51); the goal of the *Standards* is similar because they want to produce “scientifically literate” students (1996, p. ix). Both of these are similar to the Georgia Performance Standards (hereafter called GPS), whose goal is to achieve scientific literacy

(Georgia Department of Education [GADOE], 2005), and the goals of Project 2061 (American Association for the Advancement of Science [AAAS], 1990).

Their Recommendations

Scholars often quote the Committee of Ten when discussing course sequence issues, whether they are for changing it or maintaining the status quo (for example see Bardeen, 2002; Lederman, 1998; Mervis, 1998; and Schmidt, 2003). This is sensible because the most common course sequence in today's high school (biology, chemistry, and physics) was originally set out by the Committee of Ten in 1894. Educators should, however, understand a number of things about the Committee of Ten before interpreting and implementing their recommendations. For example, if one looks more closely at the report of the Committee of Ten, they write, "the selection and order of science subjects might be varied considerably to suit the needs to circumstances of different schools" (NEA 1894 p. 49). Even the Committee acknowledges that their recommendations are simply suggestions and advice, and that their advice is not applicable everywhere.

The Committee of Ten's proper name is the Committee of Ten on Secondary School Studies. These ten men were not the actual individuals who debated and constructed the recommendations first-hand. The Committee put together nine Conferences, once for each major subject, and each Conference was comprised of ten men. The two science-related Conferences were grouped as Physics, Chemistry, and Astronomy; and Natural History. The members of these Conferences were all educators or administrators, meaning that there was not a practicing scientist in either group. The recommendations made at each Conference were sent on to the Committee of Ten, who then officially compiled the various Conference reports and recommendations.

The Physics, Chemistry, and Astronomy Conference recommended that chemistry come before physics (NEA, 1894). They also suggested that both chemistry and physics should be requirements for admission to college. This second recommendation is important when one looks back at the data indicating that only one-half of students complete chemistry and only one-fifth complete physics. If our schools were legitimately still following the recommendations of the Committee of Ten, certainly many more students would be taking chemistry and physics, seeing how many of our students are admitted to college.

What the They Actually Said and What it Means Today

The above discussion of the Committee of Ten and their recommendations describe the final product and final recommendations of the Conferences and the Committee of Ten. It may be of value to understand, though, some of what went into those final recommendations, where the Conference and Committee members came from, and who their intended audience was.

Each Conference member was given an opportunity to submit a minority report, or a personal statement against a decision made by the Conference. That two of the Conferences (Physics, Chemistry, and Astronomy; and Geography) chose to do this shows that there was not universal agreement about the final recommendations. In the case of the Physics, Chemistry, and Astronomy Conference, W. J. Waggener chose to speak against the majority of his Conference, instead favoring teaching physics first. Although this opinion was submitted as a minority report, most the members of this Conference agreed with Waggener's opinion. They wrote:

It should be said that the order recommended for the study of chemistry and physics is *plainly not the logical one*, [italics added] but all the members with one exception felt that the pupils should have as much mathematical knowledge as possible to enable them to deal satisfactorily with physics, while they could profitable take up elementary chemistry at an earlier stage. (NEA, 1894, p. 119)

What the Conference means here by the “logical order” is teaching physics first, then chemistry, and then biology. In one explanation of why this order is more logical, Harris (1894) says that physics and chemistry deal with matter in its organic aspect and mechanical motion; they are mechanical and mathematical sciences. Natural history (i.e., biology) deals with organic matter and the conditions of life; it is the study of growth and progress. The disciplines require different mental capabilities, implying that physics and chemistry should come first because they require less abstract thinking. This also makes sense in light of more current research, indicating that many early high school students are still concrete thinkers (Piaget, 1970, as cited in Schunk, 2004). The other issue in the Physics, Chemistry, and Astronomy Conference’s report was with the math skills necessary for physics and chemistry, which a student would presumably not gain until later in high school. At this time in Georgia, the new GPS call for algebra and geometry to be taught in all middle school grades (GADOE, 2005), which would hopefully give incoming freshman students a solid mathematical foundation. The math issue is at the forefront of the debate today about when to teach physics, and it will be discussed later in this paper.

Educators often misinterpret the organization of science courses laid out by the Committee of Ten, quoting them as recommending biology, chemistry, and then physics.

This would be an over-simplification of the Committee's recommendations. Biology, as such, is never explicitly mentioned. Rather, natural science is broken up into botany, zoology, anatomy, physiology, and hygiene. Botany and zoology are considered as classificatory sciences, whereas anatomy, physiology, and hygiene are considered to be more advanced natural sciences. In fact, the Natural Science Conference mostly concerned themselves with elementary school science. What the Committee of Ten *actually* recommends is that botany or zoology be taught first, then chemistry, then physics, and then the higher forms of natural science (NEA, 1894). Our current science course sequence, with biology first, is somewhat true to this recommendation, in that modern biology is treated as a memorization subject, with superficial classification of organisms rather than a deep understanding of natural science. What our current science course sequence fails to achieve is the higher order natural sciences that should be taught in the higher grades, after students have gained understanding of the other science disciplines and a maturity of mind to understand biology.

Another consideration an educator should be aware of with the Committee of Ten is whom they were trying to reach with their recommendations. In 1894 high school was not meant for college preparation; the main function of high school was to “prepare for the duties of life”, and only an “insignificant percentage of graduates” went on to college (NEA, 1894, p. 51). With that in mind, the intended audience of the report of the Committee of Ten was not the same as today's audience of educational research. The question that educators should ask themselves in regards to the recommendations of the Committee of Ten is whether or not their recommendations are still valid in today's

world, where approximately 63% of high school graduates in 2002 immediately went on to college (Henry, 2002).

Finally, the Committee of Ten tried to represent various regions on the U.S. at each of the Conferences. States represented at the Physics, Chemistry, and Astronomy Conference include California, Colorado, Louisiana, Maryland, Massachusetts, Minnesota, Missouri, New Hampshire, Ohio, and South Dakota. States represented at the Natural Science Conference include California, Illinois, Indiana, Massachusetts, Minnesota, Montana, Nebraska, Virginia, and Washington, D.C. (NEA, 1894, p. 10). Today's educators, whether or not they see their state represented in either of these groups, might think about how education in their state (as well as the nation as a whole) has changed in the last 112 years, again questioning whether the Committee of Ten's recommendations are still reasonable for their state.

An American Renaissance in Science Education

The ARISE Project

The Fermi National Accelerator Lab in Illinois, with support from the U.S. Department of Energy, has proposed a foundational change for science education in America. The change they propose is the implementation of a three-year science course sequence for high school, focusing mainly on physics in the ninth-grade, chemistry in the tenth, and biology in the eleventh. The rationale behind the ARISE plan is multifaceted. Their long-term goal is to produce science-literate citizens, "especially in the changing climate in science and technology, where citizens will be voting on numerous issues on the morality and ethics in scientific research and technology today" (Bardeen, 2002, p. 27). This includes things like health, medicine, the environment, biotechnology,

bioethics, and nuclear energy. The ARISE project aspires to give students the tools of science, including an understanding of the applications and processes of science, thereby producing knowledgeable, science-literate citizens. Project 2061 and the GPA both share these two goals of producing scientifically literate students and teaching about the process of science (AAAS, 1990; GADOE, 2005).

Producing science-literate citizens is the goal of the three-year sequence. As such, the series must be treated as a whole, not as discrete science subjects that students can opt to take or not. The ARISE project is often referred to as a “physics first” program. This name, while not quite a misnomer, overlooks the fact that the ARISE program is a comprehensive sequence, rather than a simple re-ordering of discrete science courses. The curriculum is designed around “how people learn” (Lederman, 1998, p. 1). Students are engaged in explorations that reflect real science, and conclusions are based on observations and “a visualization or appreciation of principles” (Lederman, 1998, p. 22) rather than faith or blind acceptance of the teacher or textbook’s word. In fact, textbooks are used as a resource, rather than defining the curriculum. Learning the process of science rather than memorizing facts is also a goal of the GPS and Project 2061. Students should *do* science, not simply learning science but experiencing it as well (GADOE, 2005).

The science lessons are based upon real situations that are meaningful and convincing. Students learn science skills, focusing on broad experiences rather than specific facts. This is in keeping with the *Standards*, which say that science should “model and emphasize the skills, attitudes, and values of scientific inquiry” (NRC, 1996, p. 46). Each year of the sequence starts at the macroscopic level, with concrete and

familiar topics, moving towards greater detail and more abstract subject matter. The re-introduction of topics from year to year is more than mere repetition; the goal is to move towards an emphasis on the use and application of earlier topics. The first year of the ARISE program emphasizes the development of student tools such as recording and processing classroom experiences; the second and third years then apply and expand on these skills (Lederman, 1998).

The ARISE Science Sequence

The rationale for the order itself (i.e., physics, chemistry, and biology) is also multifaceted. For example, the sciences have undergone great changes in the past 100 years; biology is no longer just a descriptive science that can be taught in the early high school grades (as the Committee of Ten suggest for descriptive botany and zoology). An understanding of the physical properties of the structure and behavior of atoms is necessary for making sense of chemistry. Likewise, a chemical understanding of molecules like DNA and proteins is necessary for making sense of modern biology (Pasero, 2003). In the ARISE curriculum, biology is intended as a culminating science which is based on the physical and chemical concepts learned in physics and chemistry. The GPS, although they have no set sequence of high school courses, do say that the new biology curriculum includes more abstract concepts (GADOE, 2005), which would seem to imply that it should be taught in the later high school grades.

Various educators associated with the ARISE project (e.g., Leon Lederman, Marjorie Bardeen, and Spencer Pasero), feel that the current course sequence of biology, chemistry, and physics does not promote learning. The reasons for this are numerous. Teaching biology first is starting with the most complex of the sciences and then going

on to the sciences that underlie biology. Biology subject matter relies heavily on chemistry and physics concepts; students need these “cognitive anchors” (Gaudin, 1983, p. 343) to properly understand biology concepts. Without these anchors, students are “bewildered, bored, and demoralized” (Lederman, 1996, p. 3), and biology can really only be descriptive and based on classification schemes. In fact, students’ dislike of science is apparent in the results of a recent survey, which found that four of every ten students surveyed said they would be “unhappy if they ended up in a career with a math or science focus” (National Science Teacher’s Association [NSTA], 2006). The most significant fallacy of the current order, though, lies in the fact that many students remain concrete thinkers until later in high school; the least concrete subject (biology) is taught to the most concrete thinkers, while the most concrete science (physics) is taught to those students who are capable of more formal thinking.

Reversing the order and teaching physics first can combat some of the weaknesses in the current course sequence. For example, physics is the easiest science to understand on the concrete level and freshmen are mentally capable of understanding it (Bardeen, 2002). The *Standards* state that science should “meet the interests, knowledge, understanding, abilities, and experiences of students” (1996, p. 30). Teaching physics first can get students excited about science because it can be directly related to many of the things high schoolers do and use, like sports, cars, music, and cell phones (Zaleski & Jarvis, 2003). Chemistry and biology teachers who work at schools that have implemented the ARISE program say that their students come to them with a base of knowledge that they can utilize and that the students can “think better” about science (Pasero, 2003, p.9). Correspondingly, when students come into biology with a better base

of science skills and understanding, biology can be oriented towards understanding rather than focusing on memorization of facts. Another benefit of the ARISE curriculum is the opportunity it allows for teaching about the nature of science. Because the courses are less focused on memorization of discrete facts, teachers can focus on the processes and skills of science. Teaching about the nature of science and the processes of science are common goals of the *GPS*, Project 2061, and the *Standards* (AAAS, 1990; GADOE, 2005; NRC, 1996).

Valid Concerns

Critics of the ARISE project have numerous and valid concerns with teaching physics first (Pasero, 2003). The largest detractor from implementation of the ARISE curriculum is the math skills needed for physics. In fact, freshman physics would require the following math skills and knowledge: addition, subtraction, multiplication, division, fractions, decimals, exponents, order of operations, commutative properties, associative properties, distributive properties, ratio and proportion, percent, and graph analysis (Bardeen, 2002, p. 52). Teaching algebra in the 8th grade or teaching freshman both algebra and physics in a coordinated way would give the students the math skills they need. The new GPS already call for a spiral approach to teaching algebra, whereby it is taught in all middle school grades (i.e., 6th, 7th, and 8th grades), thereby giving freshman a good mathematical foundation (GADOE, 2005). Another answer to the math issue could be to have the math and science departments working in conjunction, developing a common vocabulary that is used to teach students in both algebra and physics (Bardeen, 2002; Pasero, 2003). In fact, the *Standards* state that “the science program should be coordinated with the mathematics program” (NRC, 1996, p. 214).

Teaching physics first would require teachers to use less math than senior level physics, but the goal of the ARISE project is to teach students to think scientifically and gain science skills, rather than memorize and drill facts. Teachers of freshman physics may have to spend more time talking about and teaching math skills, which might result in less physics content. Older high school students may have more math skills than freshmen, but as most high school science teachers know, students still have difficulty in applying what they know to physics applications, no matter what grade level they are in (Bardeen, 2002). Teaching fewer concepts doesn't necessarily mean that less physics is being learned. Sometimes less is more, and building a conceptual framework is more important than the volume of physics content taught. The new GPS concur with this when they say, "With fewer topics, teachers will be able to go deeper into appropriate materials ... In the past, there has been too much material for students to have the opportunity to master key concepts of science" (GADOE, 2005, ¶1).

Students and parents alike also tend to have "physics phobia", which involves apprehension and uneasiness about how difficult physics is and the possible resulting failure of students. According to Bardeen (2002), the best way around this particular problem is with a proactive and early public relations campaign, which will be discussed in more detail below.

Another criticism of the ARISE project is that most state tests for the 10th graders are biology heavy, meaning that students in a physics first program will be at a disadvantage. Bardeen (2002) suggests calling the College Board or the ETS for advice and explanations about tests. Transition into or out of schools that teach physics first can also cause problems, as students might come from or go to schools that teach the

traditional sequence. Placement of these students would be difficult and may negatively affect the students involved, causing them to either re-take courses they've already taken, or be placed in courses they are not ready for. Unfortunately there are not many suggestions in the current literature to combat this particular problem. A final argument of critics, which is also valid, is that there are not many physics textbooks on the market that are appropriate for freshmen. This problem could easily be overcome if textbook companies were aware of the demand.

Teachers can also have fears and concerns about teaching physics to ninth graders. Often there are not enough teachers qualified to teach a new, larger population of physics students (Bardeen, 2002; Pasero, 2003), which can be coupled with a common dislike of teaching ninth grade science, regardless of the content. Bardeen (2002) suggests treating this as an opportunity for professional development. Salary advancement can be incentive for teachers to pursue certification to teach physics, which can be possible through online courses or courses at local universities. Professional development in increasing physics content knowledge will also benefit the students, as physics can be taught from a fresh perspective. Teaching freshmen physics during summer school may help to ease the initial problem of a paucity of physics teachers and an abundance of physics students.

As can be seen, the ARISE project has both benefits and obstacles. Any change in curriculum is necessarily an important and elaborate decision.

Quantitative Research in Science Course Sequencing

There are relatively few quantitative studies that are conclusive on the most advantageous order of high school science courses. Schneider, Swanson, and Riegler-

Crumb (1997) did find that what science courses a student takes in high school “exert a strong and statistically significant influence on achievement in science” (p. 37). They categorized students into three groups based on whether they had taken at least two courses of biology, chemistry, and physics; only one of the three; or only biology or no science at all. Their study used data from the National Educational Longitudinal Study of 1988 (NELS:88) to look at what consequences courses taken have on student outcomes in math and science performance, high school graduation, and college attendance amongst other things. NELS:88 data is from a nationally representative sample of eighth-graders who were surveyed about various educational topics in 1988 when they were in the 8th grade, then surveyed every two years thereafter until they graduated in 1994, and finally surveyed one last time in 2000. For more information on this data please see the NELS website at <http://nces.ed.gov/surveys/nels88/>. What is unclear from Schneider, Swanson, and Reigle-Crumb’s study is whether there was any direct comparison between students who took biology, chemistry, and physics in that order, and those who took physics, chemistry, and biology in that order. Their results, therefore, although statistically significant, are not entirely conclusive about appropriate science course sequencing.

Glasser (2004) looked at six classes (a total of 353 students), three of which had ninth grade physics, three of which did not have ninth grade physics (this group had biology in the ninth grade). He found that the three classes that had ninth grade physics performed statistically significantly better on the math section of the PSAT in the 10th grade than the three classes that did not have ninth grade physics. On the other hand, Gaudin (1983) looked at senior classes over three years (1980-1982), calculating their performance on the Natural Sciences Reading section of the ACT test. He found that

varying the order of biology and chemistry only (i.e., comparisons between biology then chemistry and chemistry then biology) produced no sizeable effect on performance on the ACT test. While Gaudin's study had a power of greater than 0.80 and a total of 514 students, he looked only at male, college-bound students in New Orleans. Moreover, the study was done in the early 1980's, before the advent of the ARISE project, and so it does not have physics first as a variable in the study. Comparisons between Glasser's and Gaudin's data and results, therefore, may not be reasonable.

Farmington High School, in Farmington, Connecticut, is a school that has implemented the ARISE curriculum for 8 years. The new sequence has enhanced their AP program (students can opt to take AP chemistry in the 10th grade or AP biology in the 11th grade); where 50 students a year used to take AP science courses, now 261 do. This large increase in AP enrollment is beneficial to the students, and although the number of students has increased quite a bit, the mean AP test scores have remained the same (Bardeen, 2002, p. 57). This would imply that physics in the ninth grade prepares more students for success in AP level science courses. Farmington High School was initially worried that teaching physics in the ninth grade would disadvantage their students on the SAT II subject tests. However, a comparison of SAT II test scores for ninth-graders taking physics and eleventh-graders taking physics showed no difference in the scores (Bardeen, 2002, p. 57). Fears that a change in course sequence may disadvantage students on standardized testing seem to be unfounded, at least in this case study. Nevertheless, as with any case study, the results need to be reproduced at other schools in order to generalize the significance of the findings.

In another study using NELS:88 data, courses taken in high school were correlated with courses taken in the 8th grade. What Stevenson, Schiller, and Schneider (1994) found was that the level (high ability, average ability, and low ability) of course in 8th grade, but not the content of the 8th grade course (e.g., earth science versus general science), was strongly correlated with the courses a student took in high school (biology, chemistry, and physics; biology only; or no science at all). This may indicate that coordination with the middle school science department doesn't have to be a detrimental factor when changing the high school science course arrangement. The importance of these results seems to lie in the fact that coordination with middle school science, which may be difficult for high schools that feed from a number of middle schools in the area, can feel optimistic in implementing a change in high school course sequence without disadvantaging any particular group of students. This may be especially important in light of upcoming substantial changes in middle school science as per the GPS (GADOE, 2005).

Paul (2003) found that enrollment in biology, chemistry, and physics was statistically significant depending on whether or not algebra was taken in the 8th grade. While Paul's study did not compare different sequences of science courses, her results are important because they indicate that "meaningful change in math is necessary for change in science interest and enrollment" (p. 2) amongst high school students. Although Paul's research subjects were mostly low-income, minority, and immigrant students, most science educators would agree that improvements in math education go hand in hand with improvements in science education.

Implementation of Any Educational Change

Marjorie Bardeen is the editor of the seminal work on implementation of the ARISE program (2002). While not all schools will be willing or able to implement a physics first science curriculum, Bardeen's paper gives guidance on implementing any type of change in curriculum or education goals. By far and away the most important things any school can do in implementing change is to educate parents, students, administration, guidance counselors, and even college admissions offices about the benefits of the new curriculum, plan, or policy. A comprehensive public relations program, with ongoing parent and community education is imperative. Public relations campaigns need to address all concerned and involved members, and schools should not overlook non-English speaking members of the community. Non-English radio and newspapers can help to reach these members of the community.

Public relations campaigns have the potential to nip many problems in the bud. For example, involved parties (e.g., administration, parents, teachers, students, the public, and public officials) might have concerns about resource availability or lack of continuity between old and new programs. Proactive education about these kinds of things can calm fears about change. Educating parents of incoming freshmen about the merits of the new plan, along with showing them what their students will be doing and learning in the new curriculum will help to alleviate apprehension. Parents also need to know that ample learning support will be provided to students, and that a formal plan for struggling students will be in place. Furthermore, making national and state education standards available to parents can help parents understand the long-term goals of a new program.

Many educational changes will require a 4-year process, where both old and new programs are running as the school moves through a cycle beginning with an incoming

ninth grade class. Meaningful educational change needs time for implementation, and stakeholders need to be aware that results may not be immediate. In fact, new curricula should be judged after four years, not every year for realistic results (Bardeen, 2002). Sukow (as cited in Mervis, 1998) even says that 12 to 15 years (i.e., a generation of students) is necessary to study the impact of curriculum reform.

Staff development and teacher training are also imperative to the implementation of any new educational plan. In fact, the *Standards* recommend ample professional development for science teachers to improve science education as a whole (NRC, 1996). Teachers need to be given planning time before, during, and after implementation of a new curriculum. Reasonable prep loads and recruitment of teachers for the new program are important as well. Networking with schools that have already implemented a change is also good advice for any school thinking about changing curricula or educational objectives.

Student placement is a concern for any large educational change. Bardeen's (2002) advice, while specific to the ARISE project, is valid for other educational change as well. A consistent set of policies must be established before implementation to deal with students entering and leaving the system. Guidance counselors must understand the purpose of the new plan and be supportive of it in order to place students in the most appropriate places.

Schools considering implementing a physics first curriculum should decide if the physics course is going to be more conceptual or math heavy and then place students accordingly (i.e., if it is conceptual, students do not necessarily have to be placed according to prior math courses like algebra). Promoting physics as an investment in

chemistry and biology is also another consideration when addressing parent concerns about moving to a physics first curriculum. Also, administering standardized tests by course, not by grade can support the transition into a physics first program . (For example, administer the SAT II physics test at the end of the ninth grade physics course.) According to a paper from ARISE (Pasero, 2003), schools that have moved to the ARISE curriculum “tend to be satisfied with their curricula, and especially with an increased emphasis on the science process over specific content” (p. 5).

Bardeen’s paper (2002) gives an excellent case study of a school that has implemented the ARISE plan. It is a good example of pre-, during, and post-implementation plans successfully used by one school and should be looked at by anyone considering change in their school.

Conclusion

Further quantitative research is sorely needed on the topic of high school science course sequencing. Many of the papers cited in this paper are opinion papers and contain qualitative, interview-based data. What is needed is quantitative research that directly addresses the variable of course sequence. For example, data on student scores on local, state, and national standardized tests should be collected and compared for varying the order of science courses. Likewise, data on the number of advanced science courses in which students enroll and the fraction of students who declare science majors in college ought to be collected and compared between different high school science course sequences.

It is the opinion of this author, after reviewing the available literature on the topic, that a physics first plan, with a three-year required and coherent progression, may be an appropriate path to follow for schools in need of educational change in science.

Educational change, as stated above, is not an easy path to follow, nor are superficial changes that attempt to merely patch up holes, worthwhile endeavors. Education is a “complex and dynamic environment”, and reform (along with assessment of the reform) has been equated to “changing the tires on a car as you’re driving down the road” (Mervis, 1998, p. 163). If a school is not willing to make a great effort and use their resources for real change, it may be better to retain the status quo, especially if the current program is successful.

However, for schools in need of change, and for schools willing to put in the effort and resources, a change to a physics first curriculum may be advantageous. As stated above, a physics first program (physics, chemistry, and biology) teaches the sciences from most concrete (physics) to most abstract (biology). Also, this order allows for deeper biology instruction, which is based on a firm foundation of physics and chemistry principles. Freshman physics can be more conceptual than mathematical to compensate for the math skills of ninth graders. Conceptual physics, rather than debasing the discipline, can do much to teach students about scientific skills and principles rather than having them go through rote physics drills involving math.

The physics first program, however, in the opinion of this author, would be most beneficial if it were the first in a required and comprehensive three-year science sequence. If students are required to only have one science course in high school, any of the science disciplines can be taught in a rote memorization format. Requiring the three-

year series will give students scientific habits, skills, and content knowledge, which is in keeping with the *Standards* (NRC, 1996) and the GPS (GADOE, 2005).

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