Journal of Young Investigators
Peer-reviewed, Undergraduate Science Journal
Issue Six

Physics first in science education reform

by Vikram Pattanayak

Vikram Pattanayak is a Science Journalist with the Journal of Young Investigators.

Biology first, chemistry second, physics third: The traditional American high school science curriculum follows this order. Education reformers do not believe this needs to be the case. In part due to poor student performance in international science assessments, some educators are rethinking the way science should be taught in the United States.

The Third International Mathematics and Science Study (TIMSS), conducted in 1998, shows that while American fourth graders rank second in the world in science, high school seniors rank third worst out of all 21 nations studied. Similarly, in 2000, the National Center for Education Statistics conducted a study, the National Assessment of Educational Progress (NAEP), which showed only one-fifth of high school seniors meet proficiency standards - standards were set by NAEP administrators with the help of science educators. These results suggest that American high school science curricula could be more effective. Against this backdrop, many educators are calling for science education reform.

Support for the call to reform

This call for reform is supported by more than just the results of the TIMSS and NAEP studies. A leading science education reformer, Marge Bardeen, manager of the Fermi National Accelerator Laboratory Education Office, notes that what we learn in science courses could relate more to everyday life.

"Generally, I think people do not understand that science is a way of approaching problems, rather than a body of knowledge. As a result, they are often unable to assess claims and counter claims as they make choices on critical issues that face them as citizens," Bardeen says. "This is what we need to be concerned about - as we call it, scientific literacy for citizenship." Targeting high school science curricula is a way to increase science literacy, since all students, not just future scientists, must take high school science classes.

Bardeen believes a physics-first curriculum fosters coherence in education, allowing students to build upon what they already know.

Many educators and administrators believe students' poor performance on science assessments is a result of an incoherent science curriculum. As William Schmidt, United States Research Coordinator for TIMSS, wrote in a recent report, "Based on what has been learned from other countries, the best policy option is the development of a single organizing principle. This would in turn lead to a common coherent curriculum for all U.S. students."

Improving science education

To improve science education, Schmidt and others believe that high schools need to overhaul their current curricula. One such plan for reform is the physics-first curriculum, a strategic plan that reverses the order in which schools teach science.

JYI is supported by: The National Science Foundation, The Burroughs Wellcome Fund, Glaxo Wellcome Inc., Science Magazine, Science's Next Wave, Swarthmore College, Duke University, Georgetown University and many others.

Most high school science curricula start off with one year of earth science or biology, followed by a year of chemistry, and a year of physics. Marge Bardeen and Leon Lederman, a Nobel laureate and former director of Fermilab, are part of a group pushing science education reform called Project ARISE (American Renaissance in Science Education). In 1998, Bardeen and Lederman published a proposal in *Science* based on ideas that came out of Project ARISE, which aimed at reforming high school education through the physics-first curriculum. Not surprisingly, their plan heavily emphasizes the scientific method.

In the physics-first curriculum, high school students learn about the scientific process and explore real-world phenomena such as photosynthesis and gravity, giving them basic knowledge that will help them even if they do not pursue a career in the sciences. In addition to emphasizing the scientific process, as its name suggests, the physics-first curriculum has students learn physics before chemistry and biology. Bardeen and Lederman say true understanding of biology requires knowledge of chemistry, which in turn requires physics knowledge. Bardeen believes a physics-first curriculum fosters coherence in education, allowing students to build upon what they already know. "Now chemistry teachers teach some physics in their classes," she says. "They would not have to do this with physics taught first."

For example, to fully understand chemical topics such as atomic structure, students need some grounding in electrostatics, a topic taught in physics. However, if they learn physics first, they already know about electrostatics, and can apply their knowledge of physics to chemistry. This can also help teachers since they do not need to teach subjects with which they are not as familiar. In this spirit, Bardeen and Lederman suggest a three-year integrated science curriculum, along with three years of mathematics.

In their first year, Science 1, students take courses centered on physics, concentrating on the topics that will help them most in later science courses. In Science 2, they build upon their physics knowledge and learn chemistry. Then, in Science 3, students use their knowledge of physics and chemistry to understand biology. Once they finish biology, they are ready for a possible

TEST YOURELF

Sample questions from the NAEP Science Assessment run by the National Center for Education Statistics

1. Animals that reproduce sexually differ from animals that reproduce asexually in that sexually reproducing animals have

A) a larger number of offspring
B) more genetic variation among their offspring
C) offspring that are nearly identical to their parents
D) offspring that are perfectly adapted to their parents' habitat

2. X --> Y + Z + energy
The equation above represents a nuclear decay, in which nucleus X decays into particle Y and nucleus Z and releases energy. Which of the following can explain why energy is released in the decay?

A) The mass of X is less than the sum of the masses of Y and Z.
B) The mass of X is less than the difference between the masses of Y and Z.
C) The mass of X is greater than the sum of the masses of Y and Z.
D) The mass of X is greater than the difference between the masses of Y and Z.

3. Air in the atmosphere continuously moves by convection. At the equator, air rises; at the poles, it sinks. This occurs because

A) the Earth's ozone layer is thinner at the equator than at the poles
B) the Earth's magnetic field is stronger at the poles than at the equator
C) warm air can hold less water vapor than can cold air
D) warm air is less dense than cold air

Answers: 1. B; 2. C; 3. D

Source: NCES http://nces.ed.gov/nationsreportcard/science/

JYI is supported by: The National Science Foundation, The Burroughs Wellcome Fund, Glaxo Wellcome Inc., Science Magazine, Science's Next Wave, Swarthmore College, Duke University, Georgetown University and many others.

fourth year of science at the Advanced Placement level.

A different educational mindset

The physics-first curriculum is more than a cosmetic change to the structure of the curriculum. It represents a different educational mindset.

"Correctly done, it is a coherent three-year program where connections are drawn from one science to another," Bardeen said, "where concepts a student needs for year 2 are presented in year 1 where appropriate." In order to increase science literacy, the physics-first curriculum tries to present students with a logical approach to learning science that builds upon a foundation from previous courses.

"We have anecdotal reports that more students take more science with this approach so we should end up with more students who are more scientifically literate."

While this proposal looks good on paper, the question is, is it effective in the classroom? In June 2001, Project ARISE released a report on the state of physics-first programs. The report cited data from surveys of 58 public and private schools that employed a curriculum similar to the one described by Bardeen and Lederman in Science. Most had many positive things to say about the curriculum. Students generally enjoyed the new courses, and chemistry and biology teachers were excited that their students had some fundamental knowledge of physics before coming into their classes. This enthusiasm should translate to scientific literacy; Bardeen cites this as a reason for reform. "We have anecdotal reports that more students take more science with this approach," she said, "so we should end up with more students who are more scientifically literate." So far, it seems the physics-first curriculum is meeting its goals and creating student interest in science.

The need for well-controlled studies

Anecdotal evidence alone, however, cannot confirm the success of the physics-first curriculum. Richard Feynman, renowned physicist and Nobel laureate, spoke of this lack of credible studies in science education almost 40 years ago. "There is an enormous number of studies and a great deal of statistics," he said in a speech about education at the Galileo Symposium in Italy in 1964, "…but they are mixtures of anecdotes, uncontrolled experiments, and very poorly controlled experiments, so that there is very little information as a result." Following this logic, the physics-first curriculum cannot be declared a complete success without well-controlled studies showing its utility in raising science literacy.

The Project ARISE report notes the lack of hard data to test the new system, stating, "Interviewees had numerous anecdotes to support their efforts, but most of their schools had collected no numerical data for evaluative purposes." Some schools are collecting data but do not have enough to draw any conclusions yet.

"Unfortunately, in general, when schools and districts choose to make this change, they do not do it as an experiment," Bardeen said. "They do not necessarily have baseline data so that they cannot document the change with test scores, enrollment figures, etc. And for the most part, they don't see the need to do so for their own purposes."

Since schools do not study their curricula changes as controlled experiments, it will be hard to quantify the success of the physics-first curriculum.

Due to funding reasons, Bardeen's office has no plans to do a study on the

JYI is supported by: The National Science Foundation, The Burroughs Wellcome Fund, Glaxo Wellcome Inc., Science Magazine, Science's Next Wave, Swarthmore College, Duke University, Georgetown University and many others.

curriculum's impact. Despite the lack of hard supporting data, the physics-first curriculum seems to be winning over some school districts. If this continues, it may become the new standard for science education with success measured when the next international science study is conducted.

Web sites related to this topic

- Project ARISE
- TIMSS
- Nation's Report Card: Science

References

Bardeen, M.G., L.M. Lederman (1998) Coherence in Science Education. Science. 281: 178 179.

Feynman, R.P. (1999) The Pleasure of Finding Things Out. Perseus Publishing, Cambridge, MA.

National Center of Education Statistics. Pursuing Excellence: Initial Findings from the Third International Mathematics and Science Study. February 1998. http://nces.ed.gov/pubs98/twelfth/index.html [Link current as of 28 January 2003]

National Center of Education Statistics. The Nation's Report Card: Science. July 2002. http://nces.ed.gov/nationsreportcard/science/ [Link current as of 28 January 2003]

Pasero, S. [Project Arise] The State of Physics-First Programs. June 2001. http://fnalpubs.fnal.gov/archive/2001/pub/Pub-01-206.pdf [Link current as of 28 January 2003]

Schmidt, W.H. The Quest for a Coherent School Science Curriculum. September 2002. http://ustimss.msu.edu/coherentscience.pdf [Link current as of 28 January 2003]

Vikram Pattanayak is studying biochemistry and biophysics at the University of Pennsylvania. He can be reached at pattanayak@jyi.org.

JYI is supported by: The National Science Foundation, The Burroughs Wellcome Fund, Glaxo Wellcome Inc., Science Magazine, Science's Next Wave, Swarthmore College, Duke University, Georgetown University and many others.