of the previous steps.

The outline of my instructions to the students (see the box on page 76) has suggested due dates, but students receive no penalties for lateness except the self-imposed penalty of a poor final grade on the project. I give their work one of the following evaluations: *accepted* (proceed immediately to the next step), *revise* (make the changes indicated on the paper and resubmit it as soon as possible), or *need conference* (make an appointment to meet with me so I can fully explain the problems with the work). I tell the students to expect a 3 day turnaround whenever they turn in a step and to take this turnaround into account when they plan their work.

I have used this self-paced system, with some revisions, for six semesters now. The system makes it possible for me to actually enjoy independent research projects. On any given night of the school year, I have only a few steps to grade. Besides avoiding the padded cell, I can give each student more help than I could before. I feel more effective, and the students (even though they moan as they go through the system, as you can well imagine) have given it high praise in their end-of-the-year evaluations.

I encourage teachers from all disciplines—not just biology—to try having their students do independent research. It is amazing what students learn from seemingly simplistic research designs when forced to carry out these designs correctly. Your students are going to forget many of the facts that you have them memorize, but they will not forget the method by which they solved a problem of their own choosing. This self-pacing system allows you to provide your students the valuable experience of independent research while preserving your sanity. ■

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Never Playing the Game

by Robert E. Yager

Learning science—its theories, its parameters, its context—can be likened to learning all the rules of a sport—the facilities needed for playing, the scoring, the timing, the uniforms. To prepare to play, one must develop physical skills by means of strenuous exercise and conditioning. Such skill development can span great time periods and demand much energy, commitment, and sacrifice. But, most potential players are willing to devote whatever time and work are needed to succeed, because once they reach the playing field, their effort will be rewarded.

In typical science teaching, we ignore the lessons we might learn from sports. We pronounce science a fantastic game—that all should learn to play it. We spend years teaching background material, laws, rules, classification schemes, and verifications (disciplines) of the basic game. We plan activities for our students designed to develop in them specific skills that the best scientists seem to possess and use. We believe that proficiency with these skills is an important part of an education in science. It is as if we were developing conditioning exercises to train our students for the science they may actually do at a future time.

Unfortunately, however, our students rarely get to play—rarely get to do real science, to investigate a problem that they have identified, to formulate possible explanations, to devise tests for individual explanations. Instead, school science means 13 years of learning the rules of the game, practicing verification-type labs, learning the accepted explanations developed by others, and the special vocabulary and the procedures others have devised and used.

If potential athletes had to wait 13 years before playing a single scrimmage, a single set, a single quarter, how many would be clamoring to be involved? How many would do the pull-ups and the sit-ups? How many would learn the rules if there were no rewards—until college—for those who had practiced enough to play?

We expect much in science education! Could one of our problems be too much promise of what science is really like at a date much too far removed from the rigor and practice science demands? Thirteen years of preparation is a long time to wait before finding out whether a sport (or career) is as satisfying as one's parents and teachers suggest it will be.

To prepare for the game of science for 13 years without even an opportunity to play is a problem! Like athletes, science students may need to play the game frequently, to use the information and skills they possess, and to encounter a real need for more background and more skills. Such an entrée to real science in school could result in more students wanting to know and wanting to practice the necessary skills. Now, we lose too many students with only the promise that the background information and skills we require them to practice will be useful.

Paul Brandwein asserts that most students never have a single experience with real science throughout their whole schooling. He has written that we would have a revolution on our hands if every student had but one experience with real science each year he or she is in school. Are we ready for such a revolution? Can we afford not to clamor for it?

To spend 13 years preparing for a game, but never once to play it, is too much for anyone. Teachers and students alike are more motivated when they experience real questions, follow up on real curiosity, and experience the thrill of creating explanations and the fun of testing their own ideas. Real science must become a central focus in the courses we call science—across the entire K-12 curriculum. ■

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