Practical Ways to

Improve Your Science Teaching

By Dwain L. Ford

Why Improve Science Teaching?

The National Assessment of Educational Progress (1988), which compared the educational achievements of students in 13 of the most industrialized nations of the world, listed American high school students eleventh in chemistry, ninth in physics, and thirteenth in biology. Ogens[1] notes that more than 300 national reports since 1983 have pointed to the low level of scientific literacy in America and showed that the problem begins early in the educational process.

It would be a mistake to assume that the teaching in K-12 is the primary problem, since a National Science Foundation study[2] showed that 40 percent of the students who chose majors in science or engineering dropped out of those programs after taking their first college science course. Over the four years the science dropouts rose to 65 percent. Sheila Tobias attempted to determine why able, well-prepared science-oriented students turned away from science in college. Her study[3] revealed several areas that needed improvement.

Picture removed

What Are the Options?

Most suggestions for improving science teaching fit into two categories. Some deal with the atmosphere in the classroom and how it affects the student. Other recommendations focus on student development and the teacher's role as an organizer of the learning environment. Let's take a closer look at these two options.

Focus on the *Atmosphere*

Every teacher who has to do with the education of young students should remember that children are affected by the atmosphere that surrounds the teacher, whether it be pleasant or unpleasant.[4]

Ellen White recommends that this atmosphere be characterized by enthusiasm, courtesy, patience, tender sympathy, encouragement, peace, love, cheerfulness, adaptability to the needs of individual students, and friendship and companionship between the students and their teacher, as well as freedom from harshness, scolding, and severe censure.

Educational research lends support to this counsel. Brophy and Evertson[5] found that believing the students can and will learn is a key variable that separates teachers who produce good student gains from those who do not. Warmth and empathy are the most important human characteristics that contribute to success in teaching.[6] Soar and Soar[7] found that a negative classroom climate results in diminished achievement. Kauchak and Eggen[8] concluded that enthusiasm in the classroom is mostly communicated nonverbally. It is important because it enhances student attentiveness and can improve student attitudes and learning. Kauchak and Eggen also pointed out that student achievement is inversely proportional to teacher disapproval.

Research done by Tobias[9] revealed that able, well-prepared students are turned off in science and mathematics classrooms by factors like a lack of community feeling, intense competitiveness, undue fixation on grades, fear that helping someone else would lower one's grade, rudeness, and insulting or patronizing behavior. Such an atmosphere made science courses, especially the labs, very lonely places.

Johnson and Johnson[10] focused their research on the effects of working together and alone. They estimated that 90 percent of all human interactions are cooperative, and that it is vital to humanize relations between students, teachers, and administrators. They defined a humanizing relationship as one "that reflects the qualities of kindness, mercy, consideration, tenderness, love, concern, compassion, cooperation, responsiveness and friendship." Conversely, a dehumanizing relationship was described as one in which "persons are divested of those qualities that are uniquely human . . . treated in impersonal ways that reflect unconcern with human values."[11] Such persons appear unmoved by the suffering of others and become unkind, cruel, or brutal. Johnson and Johnson concluded that the goal structure of interpersonal competition—which describes most schooling—is a major dehumanizing factor. Overuse or inappropriate use of competition promotes negative and destructive relationships among students, according to their research.

Dansereau[12] found that in initial learning tasks students who studied in pairs using a systematic learning strategy outperformed students who studied alone. Those who studied a passage and summarized it for a listener outperformed the listener. The brain-based approach to learning and teaching advocated by Caine and Caine[13] shows how both the atmosphere and an activity-centered, developmental approach can enhance learning.

Focus on the Student Development and Learning

Piaget, a prominent developmental psychologist, saw the traditional goal of education as inadequate. He wrote:

The principal goal of education is to create men who are capable of doing new things, not simply of repeating what other generations have done—men who are creative, inventive and discoverers. The second goal of education is to form minds which can be critical, can verify, and not accept everything they are offered. . . . We have to be able to resist individually, to criticize, to distinguish between what is proven and what is not. So we need pupils who are active, who learn early to find out by themselves, partly by their own spontaneous activity and partly through materials we set up for them: who learn early to tell what is verifiable and what is simply the first idea to come to them.[14]

Wadsworth[15] points out that according to Piaget's theory, "development is a valid aim of education." He includes cognitive development as well as moral, social, and ego development. From the Piagetian perspective, the student's level of intellectual development determines to a large extent how learning can occur. In other words, development directs learning,

A National Science Foundation study showed that 40 percent of the students who chose majors in science or engineering dropped out of those programs after taking their first college science course. Over the four years the science dropouts rose to 65 percent.

Picture removed

rather than vice versa.[16]

Although Piaget's theory focused on child development, it has implications for teaching science both in high school and college. Piaget's four developmental stages are sensory-motor (birth to approximately two years), preoperational (approximately two to seven years), concrete operations (approximately seven to eleven years) and formal (approximately eleven years to adult).[17] The problem is that some people remain at the concrete operations level throughout life. Trifone[18] found that 75 percent of college freshmen and 60 percent of sophomores operate at the concrete operations level. Karplus[19] described the patterns and limitations of concrete and formal reasoning.

Meeting the Needs of the Concrete Reasoner

Trifone[20] concluded that students who function on the concrete level cannot learn concepts in biology that require formal reasoning ability, no matter how they are presented. Goodstein and Howe[21] came to similar conclusions in regard to chemistry. This appears to be due to the difficulty these students experience with multiple operational processes they must consider simultaneously and/or the abstract nature of the concepts.

What can the science teacher do to help concrete reasoners to succeed in college science classes? Among Trifone's suggestions are the following:[22]

1. Use less symbolic language and/or

Picture removed

reduce the complexity of the lesson or problem.

2. Use concrete models or diagrams to which the student may refer.

3. Involve the student actively in a three-step learning cycle: (a) introduce the concept in an exploratory phase in which the student observes, compares, classifies, experiments, interprets, predicts and builds models, (b) during the conceptual phase, help the students place the pattern they have discovered in proper scientific terms, (c) in the concept application phase, have students consider other examples to help them generalize the concept.

Thus, to help concrete learners, the teacher should minimize the lecture approach. He or she should rely on active, inquiry-based learning in order to induce formal reasoning.[23] Because this approach requires more time for concept development, the teacher will need to reduce the scope of topics.

Even though there is conflict over some aspects of Piaget's formal reasoner concept,[24] most of the suggestions made in this article for improving science teaching also fit into developmental models using alternative nomenclature.[25]

Most suggestions for improving science teaching fit into two categories. Some deal with the atmosphere in the classroom and how it affects the student. Other recommendations focus on student development and the teacher's role as an organizer of the learning environment.

Practical Ways to Enhance Learning in Your Classes

1. Capitalize on the interests of your students. Encourage student curiosity and follow up on it.[26] Use practical applications associated with existing interests.[27]

2. Since passivity inhibits intellectual and social development, allow your students to make decisions about their experiments.[28]

3. Avoid cookbook-type experiments[29] that merely confirm what the students already know. Design discovery labs[30] or labs with some elements of the unknown.

4. Build up students' technical and independent decision-making skills.

(a) During the last three weeks in organic chemistry, I ask students to separate the components of a binary mixture, identify each component, and make a derivative of each to confirm their identification.

(b) In my chemical separations and analysis course I devote the last three lab periods to problems from the real world. The students tackle chemical separation problems submitted to us by a local industry. Students enjoy this challenge, as they experience the satisfaction of being able to submit to industry a method to solve a problem.

5. Coordinate your lab experiment with the class assignments to maximize the overall learning experience.

(a) Design the lab to answer student questions.

(b) Divide the class into small groups and have each do variations of the experiment. This will reveal how changes in conditions affect the outcome. Have the students develop a hypothesis to explain the group data.

(c) Since students often perceive the lab to be a lonely place, let them work in pairs, except when essential skills are being developed or tested.

6. Discover your students' inaccurate ideas and design opportunities for them to gather data to correct those misconceptions.[31] Even first-year graduate students in chemistry have many misconceptions regarding chemistry and nature.[32] Since knowledge is constructed in the mind of the learner, misconceptions resist direct instruction and are best corrected by using observation, hypothesis, and generalization.

7. Seek ways to experiment and collaborate across disciplines. This will weaken or eliminate rigid subject-matter boundaries.[33] Since learning must always relate to previous knowledge, the more boundaries there are, the more difficult it is for the student to integrate the learning. Coordinate departmental science courses so that they build on one another.[34]

8. Make research an integral part of the educational process.

When students and teachers are research colleagues, neither knowing the answers to all the questions posed, but both caring *about finding them, the process of science can be learned as in no other way. Students who profit most from research are those who come to understand that it is an integral part of their undergraduate education. They develop a desire to learn science by active participation rather than by memorizing facts.*[35]

9. Get student feedback through small-group diagnosis.[36]

10. Show students that learning science can be enjoyable. The "Physics Is Fun" program in K-12, conducted by undergraduates, has changed the image of physics in Texas.[37] Hill and Berger[38] are promoting adventures in chemistry for elementary and middle schools and demonstrating that it can be exciting to learn new things at any age. The University of Texas at Austin has standing room only at their physics and chemistry "circus" programs.[39] I used to devote about four to six weeks of academy chemistry and physics labs to allow students to build equipment and perfect their demonstrations for science open house programs, which were always popular.

Conclusion

To improve your science teaching, look for ways to improve the atmosphere in your classroom. Adjust your teaching methods to match your students' level of mental development. Give students numerous opportunities to actively participate in the learning cycle.

If you are looking for some ideas for demonstrations, experiments, and resources for elementary to college level classrooms, consult Katz.[40]

Schindler offers some final advice: "Start anywhere, as long as you generate amazement, puzzlement, interest, and awe. . . . Sustaining the joy of discovery, perpetuating the romance during the disciplines of precision, is by far the teacher's greatest task once the process has begun."[41]

Dr. Dwain L. Ford is Professor of Chemistry at Andrews University, Berrien Springs, Michigan. In 1990 Dr. Ford received an Andrews University Faculty Award for Teaching Excellence. He has been voted Teacher of the Year by the Andrews University Student Association on two occasions and received the Tom and Violet Zapara Excellence in Teaching Award in 1988.

NOTES AND REFERENCES

1. Eva M. Ogens, "A Review of Science Education: Past Failures, Future Hopes." *The American Biology Teacher* 53:4 (April 1991), 199-203.

2. "The Science and Engineering Pipeline," *The National Science Foundation PRA Report 67* (April 2, 1987).

3. Sheila Tobias, *They're Not Dumb, They're Different. Stalking the Second Tier* (Washington: Science News Books, 1990).

4. Ellen G. White, *Counsels to Parents, Teachers, and Students* (Mountain View, Calif.: Pacific Press Publishing Assn., 1913), p. 191.

5. Jere E. Brophy and Carolyn M. Evertson, *Learning From Teaching: A Developmental Perspective* (Boston: Allyn and Bacon, 1976).

6. Edward H. Robinson III, Edward S. Wilson III, and Sandra L. Robinson, "The Effects of Perceived Levels of Warmth and Empathy on Student Achievement," *Reading Improvement* 18:4 (Winter 1981), 313-318.

7. Robert S. Soar and Ruth M. Soar, "Emotional Climate and Management." In Penelope L. Peterson and Herbert J. Walberg, eds., *Research on Teaching: Concepts, Findings, and Implications* (Berkeley, Calif.: McCutchan Publishing Corp., 1979).

8. Donald P. Kauchak and Paul D. Eggen, *Learning and Teaching: Research-Based Methods* (Boston: Allyn and Bacon, 1989).

9. Tobias, op. cit.

10. David W. Johnson and Roger T. Johnson, *Learning Together and Alone: Cooperation, Competition, and Individualization* (Englewood Cliffs, N. J.: Prentice-Hall, 1975), p. 14.

11. Ibid., p. 15.

12. D. F. Dansereau, "Cooperative Learning Strategies." In *Learning and Study Strategies*, C. E. Weinstein, E. T. Goetz, and P. A. Alexander, eds. (San Diego: Academic Press, Inc., 1988), pp. 103-120.

13. Renate N. Caine and Geoffrey Caine, "Understanding a Brain-Based Approach to Learning and Teaching," *Educational Leadership* 48:2 (October 1990), pp. 66-70.

14. Jean Piaget, "Development and Learning." In R. Ripple and V. Rockcastle, eds. *Piaget Rediscovered* (Ithaca, N.Y.: Cornell University Press, 1964), pp. 7-20.

15. Jean Piaget (1964) as cited in Barry J. Wadsworth, *Piaget for the Classroom Teacher* (New York: Longman, 1978), p. 99.

16. B. Inhelder, "Developmental Theory and Diagnostic Procedures." In *Measurement and Piaget*, P. Green, M. Ford, and G. Flamer, eds. (New York: McGraw-Hill, 1971).

17. Cited in Wadsworth, p. 15.

18. James D. Trifone, "Addressing the Needs of the Concrete Reasoner," *The American Biology Teacher* 53:6 (September 1991), 330-333.

19. Robert Karplus, "Science Teaching and the Development of Reasoning," *Journal of Research in Science Teaching* 14:2 (March 1977), 169-175.

20. Trifone, op. cit.

21. Madeline Goodstein and Ann C. Howe, "The Use of Concrete Methods in Secondary Chemistry Instruction," *Journal of Research in Science Teaching* 15:5 (September 1978), 361-366.

22. Trifone, op. cit.

23. Robert D. Kavanaugh and William R. Moomaw, "Inducing Formal Thought in Introductory Chemistry Students," *Journal of Chemical Education* 58:3 (March 1981), 263-265.

24. Mansoor Niaz, "Role of the Epistemic Subject in Piaget's Genetic Epistemology and Its Importance for Science Education," *Journal of Research in Science Teaching* 28:7 (September 1991), 569-580; Anton E. Lawson, "Is Piaget's Epistemic Subject Dead?" *Journal of Research in Science Teaching* 28:7 (September 1991), 581-591.

25. For example, Richard A. Duschl and Drew H. Gitomer, "Epistemological Perspectives on Conceptual Change: Implications for Educational Practice," *Journal of Research in Science Teaching* 28:9 (November 1991), 839-858.

26. Robert E. Yager and Paul Tweed, "Planning More Appropriate Biology Education for Schools," *The American Biology Teacher* 53:8 (November/December 1991), 479-483; and B. J. Wadsworth, op. cit.

27. Robert G. Hunt, "The Physics of Popping Corn," *The Physics Teacher* 29:4 (April 1991), 230-235; B. Kibble, "The Space Vehicle—Teaching Physics Through Astronomy," *Physics Education* 26 (1991), 13-18; H. K. Hobbs and T. S. Aurora, "Biomechanics of the Flexion of the Spine," *Physics Education* 26 (1991), 99-103; Carole Stearns, "Environmental Chemistry in the High School Curriculum," *Journal of Chemical Education* 65:3 (March 1988), 232-235; Carole Parravano, "Let Environmental Chemistry Enrich Your Curriculum," *Journal of Chemical Education* 65:3 (March 1988), 235-237.

28. Paul J. Germann, "Developing Science Process Skills Through Directed Inquiry," *The American Biology Teacher* 53:4 (April 1991), 243-247.

29. Andrew T. Lumpe and J. Sterly Oliver, "Dimensions of Hands-on Science," *The American Biology Teacher* 53:6 (September 1991), 345-348.

30. Robert W. Ricci and Mauri A. Ditzler, "Discovery Chemistry: A Laboratory-Centered Approach to Teaching General Chemistry," *Journal of Chemical Education* 68:3 (March 1991), 228-231.

31. Duschl and Giomer, op. cit.

32. George M. Bodner, "I Have Found You an Argument," *Journal of Chemical Education* 68:5 (May 1991), 385-388.

33. Larry L. Kirk and Larry F. Hanne, "An Alternate Approach to Teaching Undergraduate Research," *Journal of Chemical Education* 68:10 (October 1991), 839-841.

34. R. Daniel Libby, "Piaget and Organic Chemistry: The Equilibrium-Kinetic Approach for Teaching Introductory Organic Chemistry," *Journal of Chemical Education* 68:8 (August 1991), 634-637.

35. Council on Undergraduate Research, "Undergraduate Research in Science and Mathematics Education"—ACUR Position Paper. *Council on Undergraduate Research Newsletter* XI:3 (1991), 15, 16.

36. Sara Jane Coffman, "Improving Your Teaching Through Small-Group Diagnosis," *College Teaching* 39:2 (Spring 1991), 80-82.

37. Jimilyn Welborn, "The 'Physics Is Fun' Program," *The Physics Teacher* 29:7 (October 1991), 436-437.

38. Allen E. Hill and Sue Anne Berger, "Adventures in Chemistry for Elementary and Middle Schools," *Journal of Chemical Education* 66:3 (March 1989), 230-231.

39. Alice Reinarz, "Gatekeepers: Teaching Introductory Science," *College Teaching* 39:3 (Summer 1991), 94-96.

40. David A. Katz, "Science Demonstration, Experiments, and Resources: A Reference List for Elementary Through College Teachers Emphasizing Chemistry With Some Physics and Life Science," *Journal of Chemical Education* 68:3 (March 1991), 235-244.

41. Stefan Schindler, "The Tao of Teaching: Romance and Process," *College Teaching* 39 (1991), 75.