SCIENCE: EDUCATIONAL TOOLS FOR DIVERSE LEARNERS

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Abstract: This article provides background for school psychologists to use in consulting with teachers about learning problems in science. The emphasis is on (a) the conflicting forces acting on teachers — poor performance, increasing expectations, curriculum reform, and current curricular practices; and (b) how curricular interventions can help solve and even prevent learning problems. The two approaches that have dominated current practice and proposed reforms in science education during the past few decades, process, or activity-based inquiry (nonexplicit) approaches, and traditional, textbook-based, teacher directed approaches, do not align well with the research-based design features of quality science curricula diverse learners need. Considerate, well-designed instruction in the big ideas of science is proposed as an alternative to current practice and proposed reforms. Four important research-based guidelines for designing or selecting science education materials are described.

The United States ranked 13th out of 15 assessed nations for student achievement in science (Educational Testing Service, 1991). Other studies in the area of science subject matter consistently have found that American students do not perform well (American Association for the Advancement of Science, 1989; Champagne, Lovitts, & Calinger, 1989; Mullis & Jenkins, 1988; National Science Foundation & Department of Education, 1980). In fact, over the years science achievement has shown an overall downward trend (Anderson & Smith, 1986). Although approximately 40% of the nation's 17-year-old high-school students have a "moderate understanding" of science, only 7% have any degree of "sophisticated understanding" in the subject (Mullis & Jenkins, 1988). Examples of "sophisticated understanding" included the following: identifying the object that was most dense when given the volume and mass of four objects; and identifying the direction (N, S, E, or W) a shadow would fall at 8 a.m. on September 23.

In the area of science inquiry, Lawson et al. (1991) found that only 22% of 314 high school biology and chemistry students possessed the necessary science inquiry skills to discover independently simple visual concepts. The ability to discover scientific principles, such as heat causes objects to expand, would seem almost nonexistent.

Kuhn (1993) found that only 40% of a sample of adults could provide evidence for their personal theory explaining why there is unemployment, why children fail, and why criminals often return to a life of crime. And in Kuhn's study, such evidence did not have to be compelling or conclusive; it had only to be relevant and distinguishable from the theory itself. Moreover, only 60% of these adults could describe an alternative theory different...
from their own; and only 40% could
describe the evidence that would cause
them to question their theory.

In view of these low levels of science
performance, national science standards
are being developed with an eye toward
America being the best in the world by
the year 2000. These new science content
standards specify four general categories
of school science content that all students
should know: science as inquiry, science
subject matter, scientific connections, and
science and human affairs (National
Research Council, National Committee on
Science Education Standards and Assess-
ment, 1993).

The new science standards further
emphasize a commitment to science for
all. In particular, the commitment to
science for all implies inclusion not only
of those who traditionally have received
encouragement and opportunity to
pursue science, but of women and girls,
all racial and ethnic groups, students
with disabilities, and those with limited
proficiency in English. (p. 1)

The standards also intend to specify high
expectations for the learning of all
students:

For those of you who are concerned that
high expectation standards will further
widen the learning gap for disadvantaged
students, particularly when coupled with
the possibility of a national examination
system, we respond that there is consider-
able evidence that nearly all students
can learn science at considerably higher
levels than currently achieved. Low
expectations have a disproportionate
impact on low income, minority, and
disabled students. . . . Our focus group
on science for students with disabilities
tells us that the low expectations of
teachers, parents, and students them-
selves are more limiting than their
disabilities. (p. 2)

Meeting these new challenges will
clearly require major revisions in our
approach to science education. Essentially
two approaches to science education have
dominated its history: a) traditional
teacher-directed and (b) process ap-
proaches. Traditional teacher-directed
approaches stress facts, laws, and theo-
ries, and use laboratory activities as
verification exercises or as secondary
applications of concepts previously cov-
ered in class. Process approaches stress
learning how to learn science by making
laboratory activities an integral part of the
class routine (Shymansky, Kyle, & Alpor
1983).

An earlier wave of science reform that
emphasized process approaches domi-
nated America during the 25 years
following Sputnik (1956-1980). Over the
past 15 years, however, these process
approaches faded from classrooms as
American education became dominated
once again by traditional teacher-directed
approaches. This return to traditional
teacher-directed approaches has led
many science educators to review what
went wrong with the post-Sputnik science
reform and to advocate for a revival of
process approaches.

These current science curriculum
reform efforts will be evaluated with
respect to research-based design features
of quality science curricula. Considerate,
well-designed instruction in the big ideas
of science is proposed as an alternative
to current practice and constructivist
reform. This alternative is effective and
efficient for all learners and is particularly
well-suited to the learning needs of diverse
learners.

CURRENT PRACTICES IN
SCIENCE EDUCATION

The most commonly used teaching
tool is the textbook which controls 70%'
of the instructional activity in science
(Raizen, 1988; see also Patton, Polloway,
Many criticisms have been made of science
texts. Among others, they contain too
many vocabulary concepts, present ideas
in a list, are unclear and generally unable
to affect conceptual change (Lloyd, 1989;
Newport, 1990; Osborne, Jones, & Stein,
The sheer number of science concepts
included in science texts almost precludes
anything but listlike study of vocabulary
that can only be cursorily explained in the space allowed. Often the vocabulary in a 1-week science unit is greater than that of a similar unit in a foreign language course (Eylon & Linn, 1988). The quantity of new vocabulary sidetracks students into focusing on trivia while ignoring the big picture (Lochhead, 1990, p. 75).

To focus on the big picture, students must acquire a deeply integrated understanding of what they are being taught (Reif, 1990). In addition to being excessive in number, these vocabulary concepts are rarely reviewed and connected in relevant ways. For example, a popular earth science textbook introduces, among others, the concepts of volume, mass, and density in the first chapter. However, no applications are presented where students could demonstrate understanding of those concepts. Later, near the end of the book, convection is introduced without any reference to the understanding of the concepts that are so relevant to understanding convection (volume, mass, and density).

Examples of these and other inconsiderate instructional features can be found in abundance in most currently used science texts. Most phenomena are explained in terms of what happens first, second, and so on. These phenomena are rarely explained in terms of underlying forces and principles. For example, the life and death of stars is described in terms of the stages. The underlying causes for their appearance and disappearance is not described at all. Other phenomena are explained only superficially. For example, most science texts explain convection, an underlying causal principle that explains much of the dynamic phenomena of earth science, with only one paragraph. Without understanding the effects of heat on density and the interaction of pressure with changing density, a deep understanding of convection is impossible. In describing plate tectonics, one text (Prentice Hall, 1991) states that “lava erupts from the rift valley that runs the length of the ridge. When the lava wells up and hardens, the ocean floor is pushed away on either side of the ridge. The hardened lava forms new ocean floor” (p. 483). Convection explains why plates move, yet as a causal principle, it is not even mentioned.

The order of introduction of concepts also is often a problem. One text introduced conduction, convection, and radiation late in the book, after students had already learned about phenomena that are explained by these principles. Another text explained the radiation of light on page 30 and the radiation of heat on page 313 after students had most likely forgotten about radiation of light. This separate treatment of applications of the same principle can only serve to fragment student understanding at best, and at worst provide no understanding at all.

To deal with lack of understanding, many current textbooks are providing guidelines for accommodating students with disabilities in the classroom (e.g., Silver-Burdett-Ginn, Merrill, Full Option Science System). These recommendations are often made for specific handicapping conditions (e.g., students with health impairments should manipulate objects). Parmar and Cawley (1993) found that these guidelines usually will not meet the learning needs of diverse learners. Parmar and Cawley categorized most recommendations for diverse learners as nonrecommendations (e.g., “have the student [with a handicap] discuss his or her special health habits”), dangerous procedures (e.g., have the students with visual impairments taste the solutions the teacher mixes), or impractical (e.g., take the students with disabilities on a field trip). Special instructional activities such as indicating key features, or elaborating on prior knowledge, usually were not defined for the teacher. “An examination of the recommendations provided to teachers in the textbook series analyzed here shows that these teachers’ manuals are an inadequate resource for teachers” (Parmar & Cawley, 1993, p. 530).

**SCIENCE CURRICULUM REFORM**

The current proposals for science reform have many elements in common with the post Sputnik reforms and are based on a similar philosophy about learning. However, they use a new word
to describe their underlying philosophy: "constructivism." Constructivist theory describes the role of the learner in learning. Constructivists believe that learners must actively construct their own meaning by linking new learning to prior learning for themselves in order to make knowledge come alive for them (Bruner, 1986; Gilbert, Osborne, & Fensham, 1982; West & Pines, 1985).

Constructivists criticize traditional instruction that relies heavily on the textbook as being a teacher-dominant or "absorption" method. The traditional teacher-dominant approach, or absorption method, presents such a barrage of ideas that students are likely to rely on strategies that emphasize rote memorization rather than rely on strategies that foster understanding (Pauling, 1983; Roth & Anderson, 1988; Tyson & Woodward, 1989; Yager, 1983).

Perhaps the most frequently noted instructional problem is that of inert or ritual knowledge (Alexander, 1992; Perkins & Simmons, 1988; Whitehead, 1929). Ritual knowledge is knowledge that seems to exist but is not applied broadly or flexibly. Students often fail to solve problems, not because they lack the knowledge, but because they are unable to use their knowledge flexibly (Lesh, 1982; Lochhead, 1990). Research has repeatedly documented that students who demonstrate successful learning of a principle on a daily assignment often fail to use it to solve problems on another occasion (Bransford, Goldman, & Vye, 1991; Bransford, Stein, Delclos, & Littlefield, 1986; Bransford, Vye, Adams, & Perfetto, 1989; Reys, Rybolt, Bestgen, & Wyatt, 1982; Schoenfeld, 1987; Smith & Good, 1984; Whitehead, 1929). Instead of using their new knowledge, which seems to have been mastered according to classroom tests, students often revert to their inappropriate preinstructional conceptual frameworks in real-life, problem-solving situations (Mitman, Mergendoller, Marchman, & Packer, 1987; Tobin, Espinet, Byrd, & Adams 1988). "Under a thin surface layer of superficially learned science knowledge, students' pre-instructional conceptual frameworks appear to be mainly unchanged by instruction" (Duit, 1991, p. 74).

To avoid these problems, constructivists recommend presenting knowledge as a whole in a naturalistic context, without the use of textbooks and without explicit, teacher-directed instruction. Thus the instructional focus shifts from the curriculum and the teacher to the learner (Gunstone, White, & Fensham, 1986). Support for this approach grows out of the belief that explicit presentation prevents meaningful understanding. For example, Piaget argued: "Each time one prematurely teaches a child something he could have discovered for himself, that child is kept from inventing it and consequently from understanding it completely" (p. 715, Piaget, 1970).

Danley (1992) offers an illustration of what constructivism means in practice by reporting a desirable interaction between a teacher and a student:

Student: "Teacher I can't make this problem come out right."
Teacher (looking concerned and leaning over to examine the paper): "Hmmm." 
Student: "Well, what did I do wrong?"
Teacher (perplexed): "HMMMMM!
Student (frustrated): "Am I going to have to do this by myself?"
Teacher (smiling): "Hmmm." (p. 74)

Other constructivists have noted that explicit instruction in either general strategies or specific knowledge is inconsistent with constructivist learning theory and recommend the abandonment of cognitive strategy instruction in both special and general education on the grounds that it represents rote learning (DuCharme, Earl, & Poplin, 1989; Kronick, 1988; Poplin, 1988). Many constructivists believe that understanding develops through hands on activities that require students to develop, explain, elaborate, or defend their beliefs to other students. They view curriculum, not as a body of knowledge, but as a program of naturalistic activities from which the learner constructs holistic understandings.
A number of specific constructivist strategies are currently popular recommendations for reform in science education. Reports of studies evaluating these specific constructivist strategies follow.

**Change Individual Misconceptions by Presenting Contradictory Experiences**

One of the difficulties in science education is that students often have misconceptions (e.g., big objects float, small objects sink) about important science phenomena. These misconceptions have been shown to be of high frequency and to resist change through instruction (Driver & Erickson, 1983; Gilbert & Watts, 1983; Osborne & Wittrock, 1985). To remedy these misconceptions, constructivists recommend diagnosing the nature of each individual misconception and tailoring the student's experience to the specific misconception. This tailoring of instruction requires the teacher to create an episode that contradicts the specific misconception of that student (Stavy & Berkovitz, 1980; Zeitsman & Hewson, 1986). For example, to confront the misconception that big objects float and small objects sink, the teacher should show the student a small object that floats. The teacher using this "conceptual change" strategy does not define explicitly the scientific conception to replace the misconception. Rather the teacher provides the contradictory experience.

Besides the logistical problems of implementing such an approach in a large classroom (Hawkins & Pea, 1987), studies show this approach to be unsuccessful or of only limited success in eliminating misconceptions, even with small groups of students (Brna, 1987, 1988; Finegold & Gorsky, 1988; Hewson & Hewson, 1983; Roth & Anderson, 1988; Stavy & Berkovitz, 1980; White & Horwitz, 1988; Zeitsman & Hewson, 1986). Furthermore, misconceptions seem to persist, even when using conceptual change strategies (Anderson & Smith, 1986; Eylon & Linn, 1988; Gunstone, Champagne, & Klopfer, 1981; Linn, 1983; Linn & Burbules, 1988; Schneps, 1987).

The difficulty in using conflicting experience as the sole remedy for misconceptions is probably explained by the nature of student misconceptions. Most students' misconceptions are probabilistic in nature (e.g., students believe only that most big objects float, not necessarily all). With probabilistic rules, one or two conflicting observations would not be sufficient for students to reject their hypotheses, even according to the rules of scientific reasoning. A rational person would question a belief based on one or two conflicting episodes only if the belief were expected always to be true. Young children may not even be familiar with the idea that there are rules about life that they should expect always to be true. Replacing students' probabilistic misconceptions with the absolute, deterministic rules of the natural sciences would logically require a much more persuasive presentation than a few conflicting experiences.

**Concept Mapping**

Novak and Gowin (1984) developed concept-mapping to aid the identification of the misconceptions that provide a basis for planning conceptual change activities described above. This technique requires students to create maps that illustrate the links between vocabulary that students make as they learn. Concept mapping is not to be equated with teacher-constructed concept maps, and teachers are not to inform students of how concepts are linked in science. The presentation of completed maps of information, such as in a teacher-drawn diagram or model, is thought to "confuse the student, propagate errors, or foster misconceptions...". [Explicit diagrams] often create new learning problems instead of solving them" (Cullen, 1990, p. 1067). As students construct concept maps, they are believed to construct an integrated knowledge base and link new knowledge with prior knowledge. By reviewing these maps, the teacher is to identify misconceptions and use conceptual change strategies to confront those misconceptions.
Research results show that concept-mapping improved learning when compared to the traditional lecture methods used in Nigeria (Jegede, Alaiyemola, & Okebukola, 1990; Okebukola, 1990). However, when compared to traditional American instructional methods, concept mapping had little effect and sometimes even a negative effect (Allen, 1990; Heinz-Fry & Novak, 1990; Lehman, Carter, & Kahle, 1985; Stensvold & Wilson, 1990). Traditional methods used in Nigeria, which incorporate many elements of the colonial educational system, are very different from traditional instruction in America, making generalization of the Nigerian results to American settings very questionable. In a comprehensive review of 133 studies on concept mapping, Horton et al. (1993) noted a considerable difference in the average size of both achievement and attitude effects depending on the location of the study ... it may be that novelty and Hawthorne effects were perhaps much stronger for Nigerian students than for students in North America who may be accustomed to experiencing instructional and technological innovations. (p. 106).

**Activity-Based Programs**

Another common constructivist recommendation is to provide students with hands-on activities where they can figure out science principles by directly experiencing, observing, and experimenting with scientific phenomena. Constructivists point to the success of the inquiry method in the post-Sputnik reforms as support for this recommendation. Inquiry methods emphasize students figuring things out without the teacher telling them what or how to do it.

A number of reviews of the data from the post-Sputnik process approaches in science education have, in fact, concluded that these programs were more effective than traditional instruction in some significant ways (Bredderman, 1983; Lott, 1983; Shymansky et al., 1983). However, attempts to interpret these data to support the use of activity-based inquiry (nonexplicit) approaches in current science reform are problematic. Wilson and Chalmers-Neubauer (1990) evaluated the teacher roles in the use of these activity-based programs and concluded that "to limit hands-on activities to only non-directed strategies ... (which seems to be an emerging pattern in recent science texts) seems unwarranted and an unwise decision" (p. 83). Linn and Songer (1991) concluded from their experiments with activity-based inquiry instruction that students "learn to break glassware or create bubbly mixtures, but not to relate their experiments to any scientific principle" (p. 891; see also Linn, 1980). Stavy and Berkovitz (1980) also reported that instruction based on the assumption that "direct concrete experience related to the concept ... would by itself contribute to the cognitive development of the concept" (p. 679) was a "failure" (p. 680).

The activity-based inquiry programs of 20 years ago varied considerably and involved several possibly important changes from traditional science instruction of the day. Identifying the important instructional variables, inquiry, student activity, or different texts, is almost impossible. For example, the very low correlation between effect size and level of use of inquiry (nonexplicit) methods ($r = .05$) casts considerable doubt on the belief that the use of inquiry methods was a distinguishing characteristic in the success of the post-Sputnik programs (Anderson, 1983). Furthermore, Shymansky et al. (1983) found that positive effects were much stronger with teachers who used the curricular materials but had received no inservice training in inquiry methods than it was with teachers who did receive inservice training in the use of the materials. Inservice training in inquiry methods seemed to have negative effects on student learning. The notion that teachers should use inquiry (nonexplicit) methods to teach science processes, merits critical reevaluation in light of these data.

Many research reviews conclude that inquiry methods, though less effective in
teaching science subject matter, result in better science inquiry performance than explicit instruction in science subject matter (Brederman, 1983; Shayer & Adey, 1993; Shymansky et al., 1983; Staver & Small, 1990). However, these conclusions are misleading because of the way explicit instruction is usually defined; that is, the explicit treatments teach only scientific principles (e.g., volume displacement) and do not explicitly teach the skills of science inquiry at all (e.g., the scientific method). For example, several studies compared (a) an explicit treatment designed to teach the displacement principle (e.g., the amount of liquid displaced by an object is equal to the volume of the object) with (b) inquiry instruction designed to teach students to derive the principle of displacement through their own inquiry (e.g., Bay, Staver, Bryan, & Hale, 1992). Students were evaluated based on what they knew about using the scientific method to derive new principles in science. In the past, explicit treatment conditions were rarely designed to teach science inquiry skills.

It is not surprising that studies with this design generally find that inquiry teaching methods result in better science inquiry performance than explicit instruction. However, conclusions about explicit instruction for teaching science inquiry cannot be made on the basis of explicit treatments designed to teach only scientific principles. On the other hand, studies that compare inquiry instruction with instruction designed to make the strategy for science inquiry explicit generally conclude that explicit instruction is more effective. This is especially true for diverse learners (Ross, 1988; Rubin & Norman, 1992).

Explicit methods also work better than indirect methods when teaching the skills of science inquiry to future teachers (Strawitz & Malone, 1987). In other words, the data clearly suggest that a teacher should make the strategy for science inquiry explicit if students are to learn science inquiry; make scientific principles explicit if students are to learn scientific principles.

**General Strategies Instruction**

Another frequently recommended constructivistic technique is to teach general strategies for problem-solving (Schoenfeld, 1989). General strategies encompass both problem-solving strategies (e.g., working forward, working backward, means-end analysis) and other strategies, such as the scientific process and reasoning strategies (analogical and logical reasoning). This recommendation is based on the assumption that the reason students fail in problem solving is not because they lack the knowledge, but because they are unable to use their knowledge flexibly (Lesh, 1982; Lochhead, 1990). This failure is evidenced by the observation that students often jump into science problems, doggedly pursuing a particular ill-chosen approach to the exclusion of anything else. Or they may raise profitable alternatives, but fail to pursue them adequately (Lochhead, 1990).

The research literature on teaching general problem-solving strategies suggests that it is not effective in achieving better problem-solving performance (Bransford, Arbitman-Smith, Stein, & Vye, 1985; Covington & Crutchfield, 1965; Larkin, 1989; Littlefield, Delclos, Bransford, Clayton, & Franks, 1989; Reif, 1980; Savell, Twohig, & Rachford, 1986; Shaw, 1983; Wardrop et al., 1969). Strategies for problem solving are more easily learned in the context of using one's scientific knowledge base to solve problems.

Up to this point, we have attempted to provide background information for school psychologists to use in consulting with teachers about learning problems in science. The intent has been to shift the emphasis from learning disabilities to curriculum disabilities. Curriculum disabilities result from a confluence of forces that act on teachers — poor performance, increasing expectations, curriculum reform, and current curricular practices. The next section discusses how curricular
interventions can help solve and even prevent learning problems in science.

**RESEARCH-BASED DESIGN**

**FEATURES OF QUALITY TOOLS**

Four important considerations in the design of science technology, media, and materials (tools) are described in the following section. The instructional material should: (a) teach the big ideas of science, both content (e.g., convection) and process (science inquiry); (b) teach conspicuous strategies for solving problems, using visual maps and examples that refute common misconceptions; (c) scaffold the acquisition of meaningful learning by progressing on a continuum from teacher-directed learning to student-centered learning based on the proficiency level of the student; and (d) provide review that is sufficient, distributed over time, varied across contexts, and cumulative.

**Big Ideas**

The new science standards (National Research Council, 1993) suggest that only "a limited number of important concepts, principles, facts, laws, and theories" be taught and that those taught be selected because they "provide a foundation for understanding and applying science" (p. 5). Further, these national standards suggest that these foundation concepts should be what we call big ideas. According to the standards, big ideas (or foundation concepts) represent central scientific ideas and organizing principles of science. These big ideas have rich explanatory and predictive power, motivate the formulation of significant questions, and are applicable to many situations and contexts. Research supports the importance of organizing science content around big ideas for better learning and greater instructional efficiency (Mayer, 1989; Muthukrishna, Carnine, Grossen, & Miller, 1993; Niedelman, 1992; Woodward, 1994).

Perhaps the biggest idea of science is science inquiry, the process of truth-seeking which applies to all domains of knowledge. Other big ideas might include wellness in health science, conservation of matter and energy in physics, transformation of chemical energy in biology, or ecosystems in life science. Viewing science inquiry as a process for truth-seeking, rather than truth-finding, accommodates many of the current constructivist critiques of the established methods of science inquiry. For example, constructivists claim that objective knowledge (or "truth") cannot be "found," but rather is socially constructed. Viewing science inquiry as a process of "seeking" implies that the knowledge that is built by science inquiry is not conclusive, but changeable and expanding. Describing the knowledge we seek as truth conveys only that the knowledge base provides a level of predictability that effectively allows humans some control over their environs and their future that other creatures do not have.

Viewing science inquiry as truth-seeking shifts the instructional emphasis from teaching students to arrive at conclusions to teaching students when to revise their theories and conclusions. The process of recognizing conflicting data and revising one's theories accordingly is important in both formal and informal reasoning contexts (Kuhn, 1993).

**An example of a big idea in science:**

**Convection.** Earth science is usually divided into three topic areas: the solid earth (geology), the atmosphere (meteorology), and the ocean (oceanography). The principle of convection is an underlying big idea that explains many of the dynamic phenomena occurring in these three topic areas. To gain an in-depth understanding of convection, students must fully understand the interaction of density, pressure, force, and heating and cooling (see Figure 1).

For example, students must understand that heat causes a substance to become less dense, that less dense substances move from a place of high pressure to a place of low pressure, and so on. Furthermore, a specific set of facts, the big ideas about the solar system, the ocean, the solid earth, and the atmosphere, are essential in order to understand and apply
FIGURE 1. The big idea of convection and simple visual maps of some of its applications.
these principles. For example, students must know that the sun is the primary source of heat, that the tilt of the earth as it orbits around the sun causes changes in the amount of heat received in different areas of the earth (i.e., changing seasons), that the core of the earth is hot, that the ocean is very, very deep, and so on.

The way convection ties together geology, meteorology, and oceanography is illustrated along the bottom of Figure 1. Plate tectonics, earthquakes, volcanoes, and the formation of mountains are all influenced by convection in the mantle. The dynamics of the atmosphere that cause changing weather are influenced by global and local convection patterns. Similarly, the ocean currents, thermohaline circulation, and coastal upwelling are influenced by global and local convection. The interaction of these phenomena in the earth and the atmosphere result in the rock cycle, weathering, and changes in landforms. The interaction of these phenomena in the ocean and in the atmosphere result in the water cycle, wind-driven ocean circulation, El Niño, and climate in general. Learning a big idea well translates into a deep understanding of much content.

These phenomena can be described in conceptual models like those in Figure 1 that represent some basic applications of the big idea. These models are not unrelated but form part of a unified, structured convection schema. As is the case for many newer, evolving big ideas, alternative and variant explanations for these phenomena have been offered. The fact that competing theoretical explanations often exist is an aspect of science students should be made aware of, but not all the alternative and variant explanations need be taught, particularly in initial instruction.

**Strategies**

A central big idea in science is science inquiry. Science inquiry is a strategy that should be made conspicuous to students during instruction (Ross, 1988; Rubin & Norman, 1992). For example, an activity that uses an inquiry teaching method to teach science inquiry (taken from *Elementary Science Study, 1974*) can be modified to teach explicitly the procedures of science inquiry. Instead of studying an array of examples and nonexamples to figure out the critical features of an imaginary concept called a mellinark, students can be taught to draw potential mellinark figures in such a way that they actively control the variables.

It should be apparent that from one example (Drawing A in Figure 2) students cannot possibly know with certainty what a mellinark is. It could be anything with a tail, the color gray, a curved shape, and more. However, the teacher can teach the students how to draw pictures of other possible mellinarks so that different features (analogous to scientific variables) are isolated (analogous to controlling
variables) and the relevant features of a mellinark can be identified. This activity might begin by listing all the possible features that could be relevant to the concept of mellinark; for example, the barbell shape of the body, the presence of a dark spot, the presence of only one dark spot, the position of the spot, the tail, and so on. The list of variables corresponds to a list of hypotheses.

To determine the critical defining features of a mellinark, students would draw pictures that differ from the original figure in only one variable. The teacher would then tell them whether the figure they drew was or was not a mellinark. For example, Drawing B in Figure 2 does not control the variables because Drawing B differs from Drawing A in terms of many variables. Students drawing a figure that does not control variables (Drawing B) will not be able to identify any critical features of a mellinark. Students drawing figures that do control variables (Drawing C), will know that a mellinark must have a spot, for example.

A subsequent drawing could isolate and test a new variable, or it could test the range of acceptable sizes for the spot, or perhaps test whether more than one spot is possible on a mellinark. However, the objective of the strategy should be made explicit: The goal is to draw a figure that is exactly the same as the original figure except for one difference that students want to test. Similarly, the goal of the scientific method is to design an event (experiment) that is exactly the same as an observed event except for one feature (the hypothesis) that students want to test.

The mellinark activity is a simple, easily managed activity that can teach students a lot about the scientific method. Although this activity may seem quite simple, most high school students do not possess the skills to derive simple concepts from a set of examples (Lawson et al., 1991). In their study of high school chemistry and biology students, Lawson et al. found that only 20% of the students possessed the necessary science inquiry skills to systematically form and test hypotheses required to successfully identify mellinarks and other similar concepts.

**Strategies for using knowledge to solve problems.** The strategies for using content knowledge to solve problems are, in many cases, the literal application of a big idea to a problem. Students learn to use convection, for example, to predict the location and movement of a mass of water cells given the placement of the heat source. Such an application problem is analogous to the current problem facing scientists of predicting earthquakes and volcanoes given the location of plates in the earth.

A simpler example has to do with density. Figure 3 illustrates a series of examples for a strategy that teaches students how to use their understanding of density to make predictions about the direction objects will move. The first step in the strategy for learning to use density is to compare the masses of substances of equivalent volume and predict which substance will sink when they are mixed. (See Task 1 in Figure 3.) Two same-sized cubes with differing numbers of dots can be used to teach this step. A dot in a cube represents 1 gram of weight; more dots inside a cube (i.e., greater mass) means greater density.

Students then can learn the next step in the strategy, to identify equivalent volumes of substances of unequal sizes and predict which will sink when the substances are mixed. (See Task 2 in Figure 3.) Shapes of different sizes can be shown with empty cubes placed over segments of equal size to confront the misconception that more mass means greater density. By looking at the number of dots in the cube, students can tell that Substance B is more dense than Substance A, although Substance B is smaller in volume. Students can be asked to compare the density of a series of substances like those in Task 2 where the size and number of dots varies.

Finally, the last step in the strategy is to present actual substances in a naturalistic environment and ask stu-
FIGURE 3. Strategy example with density.

Task 1

Which substance is more dense?
Which substance will sink?

Task 2.

Which substance is more dense?
Which substance will sink?

Task 3.
Show students equal quantities of water and oil. Ask them to hold each container and predict which liquid will sink. After the prediction, pour the liquids together to see what happens.

dents to predict which substance will sink when the substances come together. (See Task 3 in Figure 3.)

Use visual maps to model strategies. Science content can be presented in such a way that the instruction facilitates the application of big ideas to solve problems. Besides emphasizing the explanatory nature of science, instruction that explicitly maps the organization of science's big ideas in explanatory visual illustrations can improve problem solving performance (Mayer, 1989; Mayer & Gallini, in press). An example was provided in Figure 1. In contrast to constructivist approaches where novices build maps (including misinformation), these illustrations should correspond with the manner that an expert would organize and use the information. Expert problem solvers in science differ from novice problem solvers in three important ways: (a) expert problem solvers have more knowledge, (b) the knowledge is better organized in a hierarchical structure, and (c) expert problem solvers organize this hierarchy around explanatory principles (e.g., convection). Figure 1 above illustrates a hierarchical organization around an explanatory principle, convection.

Visual maps of big ideas add to the overall "considerate" quality of the medium. A considerate medium eases comprehension in a user-friendly manner (Armbruster, 1984; Armbruster, Anderson, & Ostertag, 1987; Guzzetti, Snyder, Glass, & Gamas, 1993; Yates & Yates, 1990). In addition to explicit visual maps, considerate communication uses cues in the text or rhetoric (such as headings and signal words) to make the structure of the knowledge being communicated as clear and coherent as possible. Considerations of the structure, coherence, unity, and audience appropriateness (Kantor, Anderson, & Armbruster, 1989) and even accuracy (Champagne & Bunce, 1989) have been found to contribute to understanding.

Add a refutational aspect to communication. In addition to considerate, explicit explanations of a strategy bolstered by visual displays, examples that specifically refute common misconceptions, such as Task 2 in Figure 3, can further facilitate understanding and conceptual change (Guzzetti et al., 1993; Muthukrishna et al., 1993; Smith et al., 1993). Without Task 2 in Figure 3, the misconception that "greater mass means greater density" would not be inconsistent with the teaching presentation. With the presence of Task 2, that particular misconception is refuted. Recent research shows that planning refutations such as these is more effective than constructivist conceptual change strategies that rely on the teacher to spontaneously create conflicting experiences as needed during instruction (Smith et al., 1993).
Planning refutation requires anticipating common misconceptions likely to be learned by many students. Planning refutation requires explicit, coherent presentation of a new strategy and building into the instruction examples, particularly nonexamples, that confront those common misconceptions directly. Many studies have found that a refutational, considerate, expository text is very successful in achieving conceptual change (e.g., Guzzetti, 1990; Muthukrishna et al., 1993).

**Provide relevant experiential learning.** It is often falsely assumed that if knowledge is explicitly introduced, it must be a lecture where only the teacher is active and the students are passive. Similarly, it is falsely assumed that to involve students actively, science instruction must always be hands on experience and the teacher should not explicitly communicate information. Neither is true. The initial communication of science concepts to naive learners can be both very interactive and explicit. Table 1 contrasts effective explicit methods, traditional telling methods, and constructivist methods along four dimensions. Effective explicit instruction differs from traditional explicit instruction primarily by actively engaging the learner and including appropriate experiential activities while the teacher simultaneously explains.

Learning experiences should be relevant to understanding each big idea. Hands-on learning is not always relevant. It is often impossible to design relevant hands-on activities that effectively communicate underlying explanatory big ideas; for example, students would have difficulty figuring out a reliable theory of electricity from a pile of wires, batteries, and switches or from operating the lights and electrical appliances in their homes. Hands-on experience without coherent, explicit instruction can easily lead to misconceptions. For example, students may believe that a wire that is cut through, cannot carry electric current, and is safe to touch. Though it may not power the appliance, it can still deliver quite a shock when touched (and grounded), if one end is still connected to the power source. This is not to say that hands-on activities for applying electricity concepts are inappropriate; they would be very appropriate for applying knowledge about electrical circuits. The important distinction is that students should not be expected to derive a reliable understanding of electricity itself from hands-on experience.

To avoid misconceptions, hands-on activities should be used in initial instruction only when they are relevant to the concept being taught. Hands-on experience is relevant where texture is an important feature of understanding, as it can be in some identification and categorization activities, such as rock, leaf, or flower identification. Hands-on experience seems to detract from initial learning when texture is not a key feature of meaningful learning, as in learning how electricity works, for example (Hider & Rice, 1986).

**Scaffolding**

Once the content for instruction has been determined, the matter of how to present this content to students becomes important. Much controversy exists regarding which teaching method works best. Research shows that the more important question is when does a specific teaching method work best. The choice of teaching practice depends primarily on how well the learner performs the desired activity. The previous section illustrated initial instruction as interactive, explicit, and teacher-directed. Initial instruction assumes naïve students.

As students experience the key features of a new concept or strategy, the initial presentation should scaffold the instruction; that is, instruction should make these features clear through explicit verbal prompts or very clear models and examples. One way to scaffold instruction is through verbal prompts from the teacher; another way is through the design of the teaching examples. The first example below (Figure 4) illustrates the
TABLE 1
Features of Effective Explicit Instruction Contrasted with Traditional Telling Methods and Constructivist Methods for Initial Instruction to Naive Science Learners

<table>
<thead>
<tr>
<th>Effective Explicit Methods</th>
<th>Traditional Telling Methods</th>
<th>Constructivist Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Innovative</td>
<td>Traditional</td>
<td>Innovative</td>
</tr>
<tr>
<td>Teacher-directed</td>
<td>Teacher-directed</td>
<td>Student-directed</td>
</tr>
<tr>
<td>Experiential</td>
<td>Nonexperiential</td>
<td>Experiential</td>
</tr>
<tr>
<td>Interactive with teacher</td>
<td>Noninteractive</td>
<td>Interactive among students</td>
</tr>
</tbody>
</table>

use of teacher's verbal prompts to scaffold a strategy for controlling variables. The steps in the strategy are:

1. Select one variable (hypothesis) to test.
2. Vary the tested variable only and keep the other variables the same.
3. Interpret the results.

Figure 3 illustrated the second way to scaffold instruction — through the design of the examples. Each succeeding task was less scaffolded than the previous. Task 1 required students to compare the masses in an equivalent volume. Task 2 required students to identify equivalent volumes in two unequal-sized substances. Task 3 required application of the strategy to real examples.

Although the initial instruction is teacher-directed, students are actively involved the entire time. Therefore, the initial presentation is both experiential (for the student) and is teacher-directed. The left side of Table 2 illustrates aspects of initial instruction that work to create a user-friendly learning environment that can enable naive students to enter into new science learning successfully. Scaffolding is an apt metaphor for describing this user-friendly environment. As students progress toward proficiency in a learning objective, the scaffolding is removed and the instructional activities become less teacher-directed and more student-driven. In short, information about the learner's level of competence in the targeted instructional activity determines which practices should be used. As learners grow in competence and independence, effective instruction moves along the continuum as follows:

1. Progress from overt descriptions of the thinking processes to covert practice of those strategies.

Example: In initial instruction, the teacher states and/or models overtly the thought process involved in drawing a mellinark to test whether it needs a tail. With covert practice, the teacher says nothing. Students independently carry out the single step of drawing a figure that changes only one variable.

2. Progress from prompted to unprompted assistance.

Example: The teacher initially prompts students as they work by giving specific feedback to their mellinark drawings or specific instructions that prompt better control of the next variable. As students become more skilled at controlling variables, the prompts are no longer needed, and students successfully control the variables without teacher prompts.

3. Progress from instruction in component concepts to instruction that integrates the concepts together into a whole.
Initial Conspicuous Strategy Presentation

- Step 1. (Introduction) You're going to figure out what a mellinark is by drawing pictures that might be mellinarks.

- Step 2. (Generating hypotheses) This is a mellinark. (Teacher makes Drawing A in Figure 1.) What variables might be important in determining whether something is a mellinark or not? (As students name possibilities, the teacher lists them on the board: the barbell shape of the body, the curved shape of the body, the presence of a dark spot, the position of the spot, the presence of a tail, the size, the color, and so on, with the list of features [variables] representing a list of hypotheses.)

- Step 3. (Controlling variables) The best way to figure out what a mellinark is, is to draw a new figure that changes only one variable. The first variable I want to test is whether a mellinark needs a spot. Watch. (Teacher draws Drawing C in Figure 1.)

- Step 4. (Interpreting data) This figure is not a mellinark. From that information you can figure out one variable that defines a mellinark. What variable is that? A spot. After you draw a figure, I will tell you if it is a mellinark or not. From what I tell you, you should be able to figure out more about the variables that tell about a mellinark.

Later Scaffolded Instruction

- Step 1. (Hypothesis) (Point to the above figure.) This is a glerb. Pick a feature to test to see if it defines a glerb. What feature did you select? ....

- Step 2. (Controlling variables) Draw a figure that allows you to test for that feature.

- Step 3. (Interpret data) (For example, if the student drew this figure:)

That is not a glerb. Now, what do you know about glerbs? .... Yes, they need an opening. (Corrective feedback for drawings that do not control variables, such as below, for example:)

You did not draw a glerb. But there are a lot reasons why this is not a glerb. It could be too big; it could be the wrong shape; it could have the wrong number of sides; it could be the wrong color. You can't tell why because you changed too many things from the original figure. When you test a variable, you must keep all other variables the same. What variable were you trying to test? Whether it needs straight sides. So what variable would you change? The straight sides. What about the other variables? Keep them the same.
TABLE 2
Continuum of Effective Instructional Practices as They Relate to the Learner's Level of Performance in the Specific Type of Learning Activity

<table>
<thead>
<tr>
<th>Effective, Explicit Instruction for the Naive Student</th>
<th>Scaffolding Removed for the Proficient Student</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overt ..................................................................</td>
<td>Covert</td>
</tr>
<tr>
<td>Prompted ................................................................</td>
<td>Unprompted</td>
</tr>
<tr>
<td>Skills-Based .................................................</td>
<td>Integrated</td>
</tr>
<tr>
<td>Contrived Problems ..........................................</td>
<td>Naturalistic Problems</td>
</tr>
</tbody>
</table>

Example: The instruction in the convection cell begins with instruction in the components of the convection cell, including concepts of density and pressure; understanding of the source of heat; the cause-and-effect relations of heat, density, and pressure; and the effects of these on the movement of cells. Later instruction in the convection cell presumes knowledge of these components and provides an integrated model explaining their interactions.

4. Progress from more contrived problems to naturalistic ones using real objects.

Example: The density examples (Tasks 1 and 2) in Figure 3 are contrived in order to scaffold the strategy for using density. When students are proficient in the strategy they can then use it to predict which of two real substances will sink or float (Task 3).

An example of an activity that incorporates all of these unscaffolded features for students more proficient in science inquiry would be a lab activity where students identify rules that will predict which tubes will roll faster down a ramp (see Main & Rowe, 1993). Some of the tubes are iron, some are aluminum, some are hollow, some are solid, some are short, some are long. Students will need to apply their knowledge about controlling variables to determine which variables increase the speed of the tubes. The students would need to select appropriate pairs of tubes to roll down the ramp to test possible variables. The variables might include hollow versus solid, large versus small, heavy versus light, short versus long, and so on. Similar experience with varied unscaffolded applications such as this provide opportunities for details in understanding to be clarified further.

Review

Science is a difficult subject for most students. Therefore, the following four requirements of effective review are particularly important in science instruction; review must be sufficient, distributed, varied, and cumulative.

Sufficient. Problem-solving ability is diminished by insufficient review. Students must recall relevant knowledge to be able to use it to understand and solve problems. The mere presentation of a definition or formula for density (i.e., density is the amount of mass in a volume) or a description of convection is insufficient. Such instruction may more appropriately be called exposure for many students, including diverse learners. Only those who already know the material will likely profit from such an approach. Ample opportunities to apply the concept are necessary if students are to understand fully the relevance and utility of a concept or big idea.

Distributed. Review that is distributed over time, as opposed to massed in one learning unit, contributes to long-term retention and problem solving. This is different from a spiral curriculum, however. For example, after intensive study of density in a series of introductory
lessons, density can be reviewed sporadically as it is applied in the context of learning about pressure, the effects of heat on density and pressure, the effects of changes in density on movement and pressure, and so on. How often this review needs to occur depends somewhat on the learner.

**Varied.** Besides gradually removing scaffolding, later instruction should provide application practice that provides widely varied examples. Varied practice allows students to deepen understanding, and facilitate discussion and generalization of principles. From the initial presentation, students can only acquire a basic understanding of concepts. For example, after learning about density, students may not realize density principles are true for fragments from a piece of substance in addition to the entire substance. Students might predict that a large glob of mercury would sink, but when asked about a tiny ball from that glob, they might predict that it would float. Similarly, after the initial presentation in controlling variables, students will need much more practice controlling variables to figure out a wide range of concepts and principles in science and in other domains.

Varied practice contributes to students generating more ideas for solving problems, having higher quality ideas, asking better questions, and more successfully solving problems (Covington & Crutchfield, 1965; Schmidt & Bjork, 1992; Wardrop et al., 1969). When authentic application practice follows instruction using contrived examples, students are able to apply the strategies to different types of problems and retention improves (Olton & Crutchfield, 1969). When students fail to use acquired knowledge, it is usually associated with very few practice examples (Gick & Holyoak, 1980; Lesgold & Perfetti, 1978) or examples from an overly limited context (Bransford et al., 1989; Levin, 1979; Nitsch, 1977; Schmidt & Bjork, 1992).

**Cumulative review.** When new concepts are integrated into big ideas, cumulative review occurs. Cumulative review is important for developing an integrated understanding of the big ideas of science. For example, the initial instruction in the generic convection cell represents a cumulative review of the component concepts of density, pressure, and so on.

**SUMMARY**

The new science standards have set higher achievement goals in four areas: (a) science as inquiry, (b) science subject matter, (c) scientific connections, and (d) science and human affairs. This article has illustrated a number of instructional design considerations that can improve science instruction and result in higher achievement, particularly for diverse learners. Although diverse learners may not become expert meteorologists through the instruction described in convection, they can learn to explain such things as why mountains form or why seasons change (Muthukrishna et al., 1993). In this regard, certain aspects of effective tools and approaches that make science accessible to less able students also can make science accessible to more able students. However, current traditional teacher-lecture instructional approaches as well as the constructivist experiential reform proposals are not well suited to meet the educational needs of diverse learners.

School psychologists are encouraged to consider these instructional design considerations as guides for clinically evaluating science instruction, choosing science instructional materials, or developing instructional interventions. If the design considerations are applied to science instruction, better problem solving and higher level thinking for all learners will result. In addition, such instruction can provide the opportunity for diverse (and other) learners to acquire a usable knowledge base in the content and reasoning of science. Opportunity for diverse learners requires more than simply placing these students in a science class typically earmarked for university-bound students and adding a few teaching tips for making the content accessible to diverse learners (Parmar & Cawley, 1993).
If the only instructional methods used are those that seldom work for diverse learners, the opportunity to learn science will remain denied and the notion of learning disabilities will continue to mask the fact that many students are actually curriculum disabled. A broader perspective that includes not only students and their families but also educational tools and other aspects of the educational environment would increase the accuracy and usefulness of the diagnoses made by school psychologists. School psychologists are in a unique position to assist teachers in being critically constructive in appraising prevailing and emerging educational tools as a means of helping teachers understand the etiology of curriculum disabilities. This understanding is particularly important given the increasing diversity and growing expectations for America's students.

REFERENCES


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