

## Chapter 9. Science

Dorothy Gabel

The science education research literature of the last 10 years is replete with studies indicating that students at all levels possess many inaccurate conceptions of scientific knowledge. Although this may also have been the case in the past, it appears more prevalent now, and is at least in part caused by the rapid growth of scientific knowledge.

Analyses of textbooks indicate that they contain many more concepts than they have in the past, with fewer pages devoted to explaining or describing each particular concept. In addition, the science curriculum has shifted down, so that rather complex topics that 20 years ago were thought too difficult for students at particular grade levels are now being taught at those levels. Whether this increase of content coverage is the result of international comparisons of students in the United States with students in other countries is a moot point. The result is that students have little time to think about what they are learning, rarely see individual concepts taught in a multitude of contexts, do not see the relevance of what they are learning, frequently have negative attitudes toward science, and resort to memorizing facts and solving problems algorithmically in order to survive!

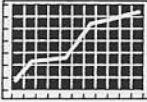
The teaching strategies and practices that research has shown to be effective in improving achievement in the teaching and learning of science all have one thing in common: they keep students' attention focused on learning. Whether this is done by pausing after asking a question before calling on a student to answer the question (wait time), by involving students in decision making (computer simulations), or by having students make comparisons with familiar situations (using analogies), all of these strategies require active learning. Many involve creating situations that challenge students' assumptions by having them make observations that are in conflict with their beliefs (cognitive

conflict), and then resolving the conflict. It is only when instruction involves or at least begins with topics that are of interest to students, and is related to their world, that students will learn in more authentic ways. That is, they will see the relationship between what they are learning and what they already know; they will think instead of memorize.

Although several of the strategies included in this review can be used by teachers and students on an individual basis, there is a growing body of evidence that learning is a social endeavor and that strategies that include interactions between students (cooperative learning) are more effective than activities in which students work alone. This appears to be true even when students work at a computer using probeware or computer simulations. Interactions among students help them clarify their own ideas and those of their peers.

All of the teaching strategies presented here (with the exception of using computer simulations) also require additional time to implement in the classroom. This increase of instructional time per concept will require educators to consider carefully which of many important concepts should be taught at particular grade levels, and which should be delayed or even omitted from the curriculum. One way this can be accomplished is to integrate science instruction across the disciplines, as suggested by the American Association for the Advancement of Science's recommendations in *Benchmarks for Science Literacy, Project 2061* (1993), and by the National Science Teachers Association in *Scope, Sequence and Coordination of Secondary School Science* (1993). A reduction of the science content included at the pre-college level has also been recommended by the National Research Council in the *National Science Education Standards* (1994).

**9.1. Learning Cycle Approach:** The use of the learning cycle approach (exploration, invention, and application) results in better content achievement, improved thinking skills, and more positive attitudes toward science.



### Research findings:

Numerous studies beginning in the 1960s and continuing today indicate that the learning cycle approach is effective in promoting both conceptual understanding and positive attitudes toward science and process skill acquisition for students at the elementary, middle school, and high school levels. When laboratory experiences (exploration and application) are combined with concept introduction (invention), positive outcomes occur. However, research on the effectiveness of laboratory instruction by itself, without concept introduction, does not support its effectiveness in improving student achievement in science.



### In the classroom:

The learning cycle approach as originally envisioned in the early 1960s for the teaching of elementary science included three phases: exploration, invention, and discovery. During the exploration phase, students explore new materials and ideas with minimum guidance. This helps students raise questions about the phenomena being explored that cannot be resolved by their accustomed way of thinking and identify patterns of regularity in the phenomena. The invention phase is more teacher-centered. Terms and concepts are introduced that explain the patterns discovered in the exploration phase. In the application phase, students apply the terms and concepts to new situations, thus learning to generalize in a broader context.

The learning cycle approach has been incorporated into a variety of science curricula and programs, particularly at the elementary level. These include *Science Curriculum Improvement Study* (SCIS) and *Biological Sciences Curriculum Study* (BSCS). Recent studies have shown that using the learning cycle approach is an effective way to determine and correct students' misconceptions, and that it can aid in improving young students' reasoning abilities. Studies indicate that all three phases are necessary, although in some instances an in-depth laboratory experience may substitute for some phases.

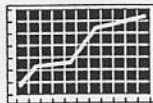
Current research indicates that modifications of the learning cycle can make it an even more effective instructional strategy. Helping students to focus their exploration by adding an engagement or prediction/discussion phase and following the application phase with evaluation appear to promote conceptual understanding. A monograph by Lawson, Abraham, and Renner (1989) provides a rich description of the use and possible modifications of the learning cycle approach.



### References:

Abraham 1989; Bybee et al. 1989; Campbell 1977; Carlson 1975; Davis 1977; Davison 1989; Glasson and Lalik 1990; Jackman, Moellenberg and Brabson 1990; Lavoie 1989, 1992; Lawson and Wollman 1976; Lawson, Abraham and Renner 1989; Lawson and Weser 1990; Marek and Methven 1991; McKinnon and Renner 1971; Purser and Renner 1983; Renner, Abraham, and Birnie 1985; Renner and Marek 1988; Rubin and Norman 1989, 1992; Scharmann 1992; Schneider and Renner 1980; Ward and Herron 1980; Westbrook, Rogers, and Marek 1990.

## 9.2. Cooperative Learning: Using cooperative learning for classroom and laboratory instruction increases student achievement, attitudes, and on-task behavior.



### Research findings:

A considerable number of research studies on the effectiveness of cooperative learning using the jigsaw approach in the classroom and the investigative approach in the laboratory indicate its usefulness for the teaching of science. Although studies in the early 1980s focused on the elementary school level, studies from the mid-1980s show that middle school and high school science students also profit from the use of these cooperative learning approaches.



### In the classroom:

The use of cooperative learning for the teaching of science has improved science achievement at all grade levels. In the classroom, cooperative groups of about four students frequently use the jigsaw approach, in which each student in a given group takes a particular role or part of a larger task. Students with the same role from each of the other jigsaw groups in the class form a new group in which each member investigates/learns his or her part of the topic. After members of this group have shared ideas and learned the material or performed the task, they return to their original group where they are responsible for sharing what they have learned and teaching students in that original group the new information.

In most investigative cooperative groups that are used for laboratory instruction, each member of the group of four takes on a different role such as recorder, checker, facilitator, or experimenter. Roles rotate with each lab investigation. In almost all studies of cooperative learning, there is positive interdependence, face-to-face interaction, individual accountability, interpersonal and small-group interactions, and group processing.

Some of the potential benefits of cooperative learning are increased achievement scores including long-term retention, more positive attitudes toward laboratory work, higher self-esteem, higher laboratory and process skill achievement, and greater on-task behavior. One area where cooperative learning has not been shown to be successful at the secondary level is increasing students' ability to solve problems. The most effective form of cooperative learning appears to occur when students are encouraged to cooperate within their group but to compete with other groups within the class.

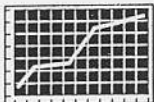


### References:

Hay 1980; Humphreys, Johnson, and Johnson 1982; Johnson and Johnson 1985a, 1985b; Jones and Steinbrink 1989, 1991; Kempa and Ayob 1991; Lazarowitz 1991; Lazarowitz et al. 1985; Lazarowitz et al. 1988; Lazarowitz and Karsenty 1990; Lazarowitz, Hertz-Lazarowitz, and Baird 1994; Lonning 1993; Okebukola 1985a, 1985b, 1986a, 1986b, 1986c; Okebukola and Ogunniyi 1984; Rogg and Kahle 1992; Sherman 1989; Slavin 1980, 1984, 1991; Tingle and Good 1990; Walters 1988; Watson 1991; Webb 1985.



**9.3. Analogies:** Using analogies in the teaching of science results in the development of conceptual understanding by enabling the learner to compare something familiar to something unfamiliar.




---

### Research findings:

Although some research studies prior to the 1980s have been conducted on the use of analogies, a new interest in this area has produced several in-depth studies which indicate that using analogies assists in concept development. This is particularly true when students have alternative conceptions about a particular concept. Research in this area tends to be qualitative in nature, and the conceptual change that occurs may not result in higher scores on multiple-choice science tests of facts and concepts.




---

### In the classroom:

Textbooks and teachers sometimes use analogies to help familiarize students with concepts that are abstract and outside their previous experience. To be effective, analogies must be familiar to students, and their features/functions must be congruent with those of the target. Since adult perspectives are not identical with those of adolescents, it is not surprising that, even though students are familiar with the physical phenomenon or event that might be used as the analogy, they are not always familiar with those features that provide the similarity to the target. Once a suitable analogy is found, considerable time must be spent by students in discussion of similarities between the analogy and the target. It is also important for students to understand how the analogy and target differ. Sometimes this can be done by using multiple analogies to teach the same concept. At other times it may be necessary to construct "bridging" analogies.

Analogies occurring in texts may be simple—based on surface similarities—or more complex (particularly in chemistry and physics)—based on similarities of function. The use of functional analogies appears to be more appropriate at the secondary level where students have developed appropriate reasoning strategies.

The discussion that occurs when using analogies not only helps students construct their own knowledge but also assists teachers in basing instruction on students' prior knowledge and existing misconceptions. Analogies may also motivate students to learn by provoking their interest. Finally, having students create their own analogies also appears to be an effective instructional strategy.

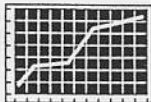



---

### References:

Brown 1992; Clement 1993; Dagher 1994; Dagher and Cossman 1992; Duit 1991b; Dupin and Joshua 1989; Flick 1991; Friedel, Gabel, and Samuel 1990; Gabel and Samuel 1986; Garnett and Treagust 1992; Glynn 1991; Griffiths and Preston 1992; Harrison and Treagust 1993; Lawson 1993; Stavy 1991; Stavy and Tirosh 1993; Sutula and Krajcik 1988; Thagard 1992; Thiele and Treagust 1994; Treagust et al. 1992; Wong 1993a, 1993b; Zeitoun 1984.

**9.4. Wait Time:** Pausing after asking a question in the classroom results in an increase in achievement.



---

### Research findings:

In most classrooms, students are typically given less than one second to respond to a question posed by a teacher. Research shows that under these conditions students generally give short, recall responses or no answer at all rather than giving answers that involve higher-level thinking. Studies beginning in the early 1970s and continuing through the 1980s show that if teachers pause between three and seven seconds after asking higher-level questions, students respond with more thoughtful answers and science achievement is increased. This finding is consistent at the elementary, middle school, and high school levels and across the science disciplines.

However, some research studies have suggested that the benefits of increasing wait time may depend on factors such as student expectations and the cognitive level of the questions. In a study of increased wait time in a high school physics class, students became more apathetic in classes where the wait time was increased. This might have occurred because this strategy did not match students' expectations of how a high school physics course should be conducted. In a study at the elementary level, a decrease in achievement was attributed to waiting too long for responses to low-level questions.



---

### In the classroom:

Increasing the wait time from three to seven seconds results in an increase in 1) the length of student responses, 2) the number of unsolicited responses, 3) the frequency of student questions, 4) the number of responses from less capable children, 5) student-student interactions, and 6) the incidence of speculative responses. In addition to pausing after asking questions, research shows that many of these same benefits result when teachers pause after the student's response to a question, and when teachers do not affirm answers immediately.

Increasing wait time also increases science achievement. Research indicates that when teachers increase their wait time to more than three seconds in class discussions, achievement on higher-cognitive-level science test items increases significantly. This holds for test items involving content, the process skills, and items involving probabilistic reasoning.

However, care must be taken in applying wait time judiciously. The optimal wait time for a given question should be adjusted to the cognitive level of the question, and student responses should be carefully monitored.

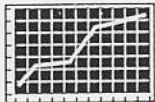


---

### References:

Altiere and Duell 1991; Anderson 1978; Fowler 1975; Garigliano 1972; Lake 1973; Riley 1986; Rowe 1974a, 1974b, 1986; Samiroden 1983; Tobin 1985, 1986, 1987; Tobin and Capie 1982.

**9.5. Concept Mapping:** The use of student-generated and teacher-generated concept maps for teaching science concepts results in improved student achievement and more positive student attitudes.



---

### Research findings:

Over 150 studies on concept mapping have been reported since the late 1970s. A careful meta-analysis conducted by Horton et al. of 19 studies that qualified out of 133 reported by 1990 indicates positive effects on student achievement and attitudes. (The analysis included only studies that occurred in actual classrooms using control groups and in which sufficient quantitative data were reported.) One hundred references related to concept mapping have been reported by Al-Kunifed and Wandersee.



---

### In the classroom:

A concept map is a schematic diagram or semantic network that includes concepts arranged in a hierarchical order linked by words that form propositions. Concept maps can be made by teachers or students either individually or in a group. They are used in a variety of situations, such as in an overview at the beginning of a unit, during instruction to assess conceptual understanding, and at the end of a unit to review for a test or to evaluate learning. Concept mapping in the science classroom, particularly for biology instruction, improves science achievement and attitudes. The use of concept maps appears to be more beneficial at the end of a unit than at the beginning. Although there appears to be no difference in student achievement whether the maps are constructed by the teacher or by the students, there are greater gains in achievement when students supply the key terms to construct the maps.

In addition to their direct use in classroom instruction, concept maps also have other educational benefits for students. They can help teachers become more effective and can be used as an aid in curriculum development.

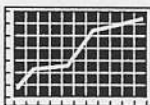


---

### References:

Al-Kunifed and Wandersee 1990; Beyerbach and Smith 1990; Fisher 1990; Horton et al. 1993; Hoz, Tomer, and Tamir 1990; Novak and Gowin 1984; Novak and Musonda 1991; Pankratius 1990; Roth 1994; Roth and Roychoudhury 1992; Starr and Krajcik 1990; Wallace and Mintzes 1990; Willerman and Mac Harg 1991; Wilson 1994.

**9.6. Computer Simulations:** Using computer simulations to represent real-world situations enables students to become more reflective problem solvers and to increase their conceptual understanding.



---

**Research findings:**

Data from a survey of secondary science departments in the fall of 1992 indicate that 49 percent of those surveyed used computers in teaching science at least occasionally. Although the most common use of computers was for simulations, only 18 percent of the schools surveyed indicated that computers were used once or twice per week.

Convincing research studies on the use of simulations in science instruction at the upper elementary and secondary levels are needed to justify more widespread and frequent use of this strategy.



---

**In the classroom:**

Many scientific models are difficult or impossible to observe, or are so complex that they are difficult to study in the laboratory. In chemistry, for example, students cannot observe the motion of atoms in solids, liquids, and gases because of their size. In physics, the study of velocity and acceleration becomes difficult in the laboratory because the observer has to account for friction. In biology, studies of genetics might have to extend over a prolonged time period.

Computer simulations can overcome these obstacles by simplifying complex systems, and then incorporating the various complexities to show their effect on the system. Use of simulations tends to result in increased achievement on complex and difficult concepts in less time than conventional instruction. Simulations (sometimes referred to as microworlds) can be used by instructors in classroom settings; however, the most effective use is by students either alone or in small groups. This permits guided exploration by students of the variations of the system, leads to better conceptual understanding and achievement, and appears to increase students' problem-solving and process skills. As with analogies, the use of simulations may create misconceptions, and so requires careful teacher attention to the understandings (or misunderstandings) produced. They should not be used exclusively in place of laboratory activities, and care must be taken by teachers to help students identify the limitations of the simulated models.



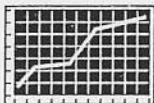
---

**References:**

Berge 1990; Berger 1982, 1984, 1987; Choi and Gennaro 1987; diSessa 1988; Faryniarz and Lockwood 1992; Geban, Askar, and Ozkan 1992; Hakerem, Dobrynina, and Shore 1993; Jungck and Calley 1986; Kinnear 1983; Krajcik 1989; Lehman 1994; Linn 1988; Njoo and de Jong 1993; Rivers and Vockell 1987; Simmons 1989; Wells and Berger 1986; White and Frederickson 1989; White and Horowitz 1987, 1988; Williamson and Abraham 1995; Wiser and Kipman 1988; Zeitsman and Hewson 1986.



**9.7. Microcomputer-Based Laboratories:** Using computers to collect and display data from science experiments enables students at the secondary level to understand science concepts and learn to use science process skills.



---

### Research findings:

Although the research in this area is somewhat limited, several studies indicate the value of students' participation in microcomputer-based laboratories; these studies outweigh other studies showing no improvement over traditional laboratory approaches. The use of computers in the science classroom is still limited in scope, and hence only a limited number of studies have been conducted to date.



---

### In the classroom:

In a microcomputer-based laboratory (MBL) experiment, students use electronic probes that are interfaced with a microcomputer that directly records and graphs data being collected. This enables students to immediately see the trends in the data as they are being collected, and to focus on the meaning of the experiment rather than on completing a data table or making a graph. This may enable students to question their prior beliefs and to ask new questions related to the experiment. The effectiveness of using these scientific probes depends greatly on the instructional sequence in which they are used.

In comparisons with traditional instruction, MBL use frequently results in a different set of outcomes. For example, students using MBLs are better able to interpret graphs, whereas students with conventional laboratory experiences are better able to construct graphs. Because both are important instructional outcomes, it is recommended that MBLs be interspersed with conventional laboratory experiences, rather than used exclusively.



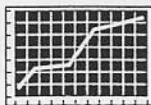
---

### References:

Adams and Shrum 1990; Beichner 1990; Berger 1987; Brasell 1987; Friedler, Nachmias, and Linn 1990; Grayson and McDermott 1989; Jackson, Edwards, and Berger 1993; Krajcik and Layman 1989; Lewis and Linn 1989; Linn and Songer 1988; Mokros and Tinker 1987; Nakhleh and Krajcik 1994; Tinker 1985; Wise 1988; Wisner and Kipman 1988.



**9.8. Systematic Approaches in Problem Solving:** Planning the solutions to mathematical chemistry and physics problems in a systematic way enables students to more frequently solve the problems correctly.



---

### Research findings:

Most of the studies on mathematical problem solving in the sciences have examined processes students use to solve chemistry and physics problems. Mathematical problem solving in biology focuses on genetics, and research on using a systematic approach in solving these types of problems is lacking. Polya in the 1940s suggested the four-step approach described below, which researchers have modified over the years.



---

### In the classroom:

Expert problem solvers take a considerable length of time in planning and analyzing a given problem before using mathematics for its solution. Novice problem solvers appear to use cues in the problem to search their memory for a formula or algorithm that they can use to solve the problem. Unfortunately, if superfluous information is given in a problem, this frequently causes them to use an incorrect formula.

Novice problem solvers can improve their problem solving skills if they use a systematic approach such as: 1) understanding the problem; 2) devising a plan; 3) carrying out the plan; and 4) looking back. In order to understand the problem, students must identify what information is given in the problem, and what is sought. Sometimes drawing a picture (such as a force diagram in physics or a picture of what is happening on the molecular level in chemistry) aids in understanding the problem. Using this information, students then formulate plans for the problem solution. Helping students categorize problems into specific types enhances the planning stage. The final step, looking back, involves checking the mathematics used, the execution of the plan, and the reasonableness of the answer.

These steps are not necessarily sequential in nature. For example, during the planning stage it may be necessary to revert to the understanding phase to recall additional information needed or to eliminate superfluous information. The steps do not come naturally to students, and need to be illustrated and practiced when students are taught to solve problems. In addition, because using a systematic approach requires more time than simply using a formula, care must be taken to assign fewer, but more varied, problems for practice, and to allow more time for problem solving on tests.

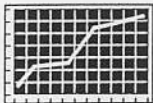


---

### References:

Bhaskar and Simon 1977; Bunce et al. 1990; Bunce, Gabel, and Samuel 1991; Bunce and Heikkinen 1986; Cameron 1985; Chi, Feltovich, and Glaser 1981; de Jong and Ferguson-Hessler 1986; Frank and Herron 1987; Hegarty 1991; Heller and Hollabaugh 1992; Heller, Keith, and Anderson 1992; Heller and Reif 1984; Kramers-Pals, Lambrechts, and Wolff 1982; Larkin 1980; Lesgold and Lajoie 1991; Mettes et al. 1980; Polya 1945; Reif 1983; Reif and Heller 1982; Schoenfeld 1978; Stiff 1988; Van Heuvelen 1991; Wright and Williams 1986.

**9.9. Conceptual Understanding in Problem Solving:** Understanding concepts qualitatively enables students to solve quantitative problems in physics and chemistry more effectively.



---

### Research findings:

Research at the secondary and even post-secondary level on understanding of basic concepts that are involved in solving many chemistry and physics problems (such as mass and volume) indicate that students do not understand these concepts. This is confirmed by many research studies on problem solving in which students solve problems aloud. Although there is a limited amount of research to indicate that understanding basic concepts qualitatively improves mathematical problem solving, it appears that this would be the case.



---

### In the classroom:

Many secondary students use algorithms to solve chemistry and physics problems that require the use of mathematics. They substitute data given in a problem into a formula (or use the factor-label method), perform appropriate mathematical operations, and arrive at a correct solution. However, when asked about the meaning of what they have done or requested to describe the variables and the relationship among the variables involved, they are unable to do so.

There is some evidence that having students perform numerous problems in this manner does not necessarily lead to conceptual understanding. If conceptual understanding is the expected outcome of science instruction, a more reasonable approach would be to emphasize a qualitative understanding of the underlying concepts first, and then to use mathematical problem solving to provide deeper insight into the concepts. For example, many students can calculate the density of a solid, yet when shown samples of identical mass but different volumes, are unable to serial order the samples by density. It is unlikely that having students solve numerous density problems by substituting values into the density formula will help them distinguish between density and volume.

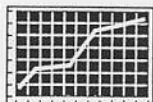


---

### References:

Anamuah-Mensah 1986; Bhaskar and Simon 1977; Bunce, Gabel, and Samuel 1991; Chi, Feltovich, and Glaser 1981; de Jong and Ferguson-Hessler 1986; Finegold and Mass 1985; Gabel 1981; Gabel, Sherwood, and Enochs 1984; Gorodetsky and Hoz 1980; Griffiths, Pottle, and Whelan 1983; Hegarty 1991; Heller, Keith, and Anderson 1992; Herron and Greenbowe 1986; Larkin 1980, 1983; Larkin et al. 1980; Lythcott 1990; McMillan and Swadener 1991; Niaz and Robinson 1989; Reif and Heller 1982; Robertson 1990; Schmidt 1990; Sumfleth 1988; Sweller 1988; Ward and Sweller 1990.

**9.10. Science-Technology-Society:** Using a Science-Technology-Society approach in the teaching of science results in an increase in the number of students taking additional science courses and advanced-level courses, as well as changing students' attitudes towards science and their understanding of the nature of science and its relationship to technology and societal issues.



---

### Research findings:

Studies in this area are somewhat limited. Most comparative studies have been performed by one major researcher, and include students in grades four through nine. However, AAAS's *Project 2061* and the National Research Council's draft of the *National Science Education Research Standards* endorse the inclusion of science, technology, and society issues in the curriculum. Furthermore, curriculum developers in Canada and in the United Kingdom include this approach in widely used national curriculum projects at the secondary levels.

There is little evidence that STS increases students' knowledge of facts, concepts, or principles, but no evidence that it decreases it. When STS is integrated into the curriculum as a major thrust (not as vignettes), positive outcomes occur. These include an increase in understanding the process and applications of science, as well as improving creativity and attitudes toward science. An additional benefit found in Canada was improving students' understanding of science as a way of knowing. In the United Kingdom, STS was found to dramatically increase the number of students taking additional science courses. In the U.S., new curricula have been developed by the ACS in chemistry using this approach at the middle school and high school levels.



---

### In the classroom:

Educators should consider using Science-Technology-Society (STS) approaches to the curriculum as a way to make science more relevant to students' lives. STS issues can be included as vignettes as a small part of the curriculum. However, based on the research results, a more promising approach is to use STS as an entire course that has as its objectives the development of an appreciation of the interactive nature of science, technology, and society; knowledge of technology as applications of science; the ability to respond critically to technology issues; or a combination of these goals with teaching science concepts and principles.



---

### References:

Aikenhead and Ryan 1992; American Association for the Advancement of Science 1993; Barker 1993a, 1993b; Ben-Zvi and Gai 1994; Bybee 1987; Campbell et al. 1994; Hart and Robottom 1990; McFadden 1991; Myers 1988; National Research Council 1994; National Science Teachers Association 1982, 1991; Ramsden 1992, 1994; Rosenthal 1989; Rubba, McGuyer, and Wahlund 1991; Sutman and Bruce 1992; Waks and Barchi 1992; Winther and Volk 1994; Yager and Tamir 1993; Yager, Tamir, and Mackinnu 1993; Yager and Yager 1985; Zoller et al. 1990.

**9.11. Real-Life Situations:** Using real-life situations in science instruction through the use of technology (films, videotapes, videodiscs, CD ROMS) or through actual observation increases student interest in science, problem-solving skills, and achievement.



---

### Research findings:

Research support for the use of real-life situations (or simulations of these) in classroom instruction continues to increase as the technologies for bringing real-life situations into the classroom become more available to teachers. The leading research group in the United States using anchored instruction to increase middle school students' problem-solving skills is located at Vanderbilt University. Several of the bibliographic entries include summaries of its work.



---

### In the classroom:

Students frequently compartmentalize learning. For example, many students who have studied mathematics are unable to apply it in solving problems in chemistry and physics. Many fail to associate the variable "x" used extensively in algebra problems to letters standing for variable names in physics problems. Even within the science course itself, many students fail to recognize that the topics they are studying apply to real-life situations. One reason proposed for this lack of transfer is that problem solving and learning have not taken place in real-world contexts. The use of videotapes or discs depicting real-life situations or simulations of these (either alone or in tandem with computers) makes it much more feasible to teach using real-world situations.

Videodiscs using simulations of real-world problem-solving situations, developed to improve students' mathematics and science problem-solving skills, have been used successfully by middle school students at several different sites. Although results indicate no difference in standardized test achievement, this finding was considered to be positive because time normally spent on conventional instruction was reduced to allow for the use of the problem-solving videodiscs which did have a positive effect on students' problem-solving skills. The instruction surrounding the use of the videodiscs was very carefully structured by classroom teachers, and this appears to be an important factor in the use of technology in the classroom.

The use of interactive videodiscs is also proving to be an important instructional strategy. Guidance in using the videodiscs is programmed and controlled by a computer that directs students' attention and frequently requires students to make decisions about their own learning. Effective programs, particularly at the secondary and college levels, show that student achievement and attitudes improve with their use, and that in some cases interactive videodiscs are an effective substitute for conventional laboratory experiences such as dissections in biology.



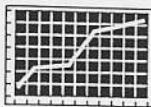
---

### References:

Bereiter and Scardamalia 1989; Bohren 1993; Brown 1992; Brown, Collins, and Duguid 1989; Cobb 1994; Cognition and Technology Group at Vanderbilt 1992, 1993; Dawson 1991; Hofmeister, Engelmann, and Carnine 1988; Kinzie, Strauss, and Foss 1993; Leonard 1992; Lockhart, Lamon, and Gick 1988; Meyers 1993; Savenye and Strand 1989; Smith and Jones 1988.



## 9.12. Discrepant Events: Using discrepant events in science instruction results in cognitive conflict that enhances students' conceptual understanding.



### Research findings:

There is little direct research evidence that using discrepant events (occurrences in nature that are at odds with students' current thought) promotes conceptual understanding. However, two of the practices included in this chapter (Learning Cycle Approach and Real-Life Situations) are thought to be effective because they frequently include discrepant events. Discrepant events are one form of anomalous data that help students focus on their prior conceptions, a step that is thought to be necessary if students are to alter their conceptions so that they become closer to the accepted scientific view. During the exploration phase of the learning cycle, students may confront anomalous data, or such data may be included in instruction based on real-world situations. The reference by Chinn and Brewer provides the theoretical framework for using anomalous data in science instruction.



### In the classroom:

Many science teachers use discrepant events frequently in their teaching, and this practice has been advocated by authors of methods texts over the years. An example of a discrepant event from physics instruction would be to drop a Styrofoam and a steel ball of equal volumes from the same height at the same time and note that both hit the floor at the same time. Because most students think that the heavier ball will hit first, the event is discrepant.

Although discrepant events frequently take the form of demonstrations, all demonstrations do not necessarily include discrepant events. Discrepant events can be built into hands-on activities that students actually perform and can be included in computer simulations and on videodiscs.

Just because students view or experience something that is discrepant does not guarantee that they will learn from the situation. Students may ignore or reject it. In order to maximize its effectiveness, the anomalous data must be credible and unambiguous. A recommended strategy for effective instruction includes the following steps: 1) consider a physical scenario of unknown outcome; 2) predict the outcome; 3) construct one or more theoretical explanations; 4) observe the outcome; 5) modify the theoretical explanation; 6) evaluate competing explanations; and 7) repeat the previous steps with another discrepant event illustrating the same theory or concept.



### References:

Chinn and Brewer 1993; Dreyfus, Jungwirth, and Eliovitch 1990; Duit 1991a; Lawson 1990; Linn and Songer 1991.

## References

- Abraham, M.R. 1989. "Research and Teaching: Research on Instructional Strategies." *Journal of College Science Teaching* Vol. 18: 185-187.
- Adams, D.D. and J.W. Shrum. 1990. "The Effects of Micro-computer-based Laboratory Exercises on the Acquisition of Line Graph Construction and Interpretation Skills by High School Biology Students." *Journal of Research in Science Teaching* Vol. 27: 777-787.
- Aikenhead, G.S. and A.G. Ryan. 1992. "The Development of a New Instrument: Views on Science-Technology-Society." *Science Education* Vol. 76: 477-491.
- Al-Kunifed, A. and J.H. Wandersee. 1990. "One Hundred References Relating to Concept Mapping." *Journal of Research in Science Teaching* Vol. 27: 1069-1075.
- Altieri, M.A. and O.K. Duell. 1991. "Can Teachers Predict Their Students' Wait Time Preferences?" *Journal of Research in Science Teaching* Vol. 28: 455-461.
- American Association for the Advancement of Science. 1993. *Benchmarks for Science Literacy, Project 2061*. New York: Oxford University Press.
- Anamuah-Mensah, J. 1986. "Cognitive Strategies Used by Chemistry Students to Solve Volumetric Analysis Problems." *Journal of Research in Science Teaching* Vol. 23: 759-769.
- Anderson, B.O. 1978. *The Effects of Long Wait-Time on High School Physics Pupils' Response Length, Classroom Attitudes and Achievement*. Doctoral dissertation, University of Minnesota. *Dissertation Abstracts International* Vol. 39: 3493A. (University Microfilms No. 78-23, 871.)
- Barker, V. 1993a. *16 Year Old Students' Understanding of the Conservation of Matter in Chemical Reactions* (Science Education Research Paper 93/03). York, UK: Department of Educational Studies, University of York.
- Barker, V. 1993b. "An Investigation of 16-18 Year Old Students' Understanding of Basic Chemical Ideas." In *European Research in Science Education. Proceedings of the First Ph.D. Summer School*, P. Lijns, editor (pp. 175-183). Utrecht: CD-b Press.
- Beichner, R.J. 1990. "The Effect of Simultaneous Motion Presentation and Graph Generation in a Kinematics Lab." *Journal of Research in Science Teaching* Vol. 27: 803-815.
- Ben-Zvi, N. and R. Gai. 1994. "Macro- and Micro-Chemical Comprehension of Real World Phenomena." *Journal of Chemical Education* Vol. 71: 730-732.
- Bereiter, C. and M. Scardamalia. 1989. "Intentional Learning as a Goal of Instruction." In *Knowing, Learning, and Instruction: Essays in Honor of Robert Glaser*, L.B. Resnick, editor (pp. 361-392). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Berge, Z.L. 1990. "Effects of Group Size, Gender, and Ability Grouping on Learning Science Process Skills Using Microcomputers." *Journal of Research in Science Teaching* Vol. 27: 747-759.
- Berger, C. 1982. "Attainment of Skill in Using Science Processes. I: Instrumentation, Methodology and Analysis." *Journal of Research in Science Teaching* Vol. 19: 249-260.
- Berger, C. 1984. "Learning More than Facts: Microcomputer Simulation in the Science Classroom." In *Intelligent School House: Readings on Computers and Learning*, D. Peterson, editor. Reston, VA.
- Berger, C. April 1987. *Misconceptions and Thin Conceptions of Teachers Using Microcomputer-based Laboratories*. Paper presented at the meeting of the American Educational Research Association, Washington, DC.
- Beyerbach, B. and J. Smith. 1990. "Using a Computerized Concept Mapping Program to Assess Preservice Teachers' Thinking About Effective Teaching." *Journal of Research in Science Teaching* Vol. 27: 961-972.
- Bhaskar, R. and H.A. Simon. 1977. "Problem Solving in Semantically Rich Domains: An Example from Engineering Thermodynamics." *Cognitive Science* Vol. 1: 193-215.
- Bohren, J.L. 1993. *Science Learning and Interactive Video-disc Technology*. Paper presented at the annual meeting of the International Visual Literacy Association, Pittsburgh, PA. (ERIC Document Reproduction Service No. ED 363 286.)
- Brasell, H. 1987. "The Effect of Real-Time Laboratory Graphing on Learning Graphic Representations of Distance and Velocity." *Journal of Research in Science Teaching* Vol. 24: 385-395.
- Brown, A.L. 1992. "Design Experiments: Theoretical and Methodological Challenges in Creating Complex Interventions in Classroom Settings." *Journal of the Learning Sciences* Vol. 2: 141-178.
- Brown, D.E. and J. Clement. 1992. "Using Examples and Analogies to Remediate Misconceptions in Physics: Factors Influencing Conceptual Change." *Journal of Research in Science Teaching* Vol. 29: 17-34.
- Brown, J.S., A. Collins, and P. Duguid. 1989. "Situated Cognition and the Culture of Learning." *Educational Researcher* Vol. 18, No. 1: 32-42.
- Bunce, D.M. and H. Heikkinen. 1986. "The Effects of an Explicit Problem-Solving Approach on Mathematical Chemistry Achievement Using Problem Categorization." *Journal of Research in Science Teaching* Vol. 28: 11-20.
- Bunce, D.M., K. Baxter, A. DeGennaro, B. Jackson, J. Lyman, M. Olive, and B. Yohe. December 1990. *Teaching Students to Solve Chemistry Problems—A Cooperative Research Project*. Paper presented at the annual meeting of the National Science Teachers Association, Washington, DC.
- Bunce, D.M., D.L. Gabel, and K.B. Samuel. 1991. "Enhancing Chemistry Problem-Solving Achievement Using Problem Categorization." *Journal of Research in Science Teaching* Vol. 28: 505-521.
- Bybee, R.W. 1987. "Science Education and the Science/Technology/Society (STS) Theme." *Science Education* Vol. 71: 667-683.
- Bybee, R.W., C.E. Buchwald, S. Crissman, D.R. Heil, P.J. Kuerbis, C. Matsumoto, and J.D. McInerney. 1989.

- Science and Technology Education for the Elementary Years: Frameworks for Curriculum and Instruction.* Washington, DC: National Center for Improving Science Education.
- Cameron, D.L. 1985. "A Pictorial Framework to Aid Conceptualization of Reaction Stoichiometry." *Journal of Chemical Education* Vol. 62: 510-511.
- Campbell, B., J. Lazonby, R. Millar, P. Nicolson, J. Ramsden, and D. Waddington. 1994. "Science: The Salters Approach—A Case Study of the Process of Large Scale Curriculum Development." *Science Education* Vol. 78: 415-447.
- Campbell, T.C. 1977. "An Evaluation of a Learning Cycle Intervention Strategy for Enhancing the Use of Formal Operational Thought by Beginning College Physics Students." *Dissertation Abstracts International* Vol. 36, No. 7: 3903A.
- Carlson, D.A. 1975. "Training in Formal Reasoning Abilities Provided by the Inquiry Rose Approach and Achievement on the Piagetian Formal Operational Level." *Dissertation Abstracts International* Vol. 36, No. 11: 7368A.
- Chi, M.T.H., P.S. Feltovich, and R. Glaser. 1981. "Categorization and Representation of Physics Problems by Experts and Novices." *Cognitive Science* Vol. 5: 121-152.
- Chinn, C.A. and W.F. Brewer. 1993. "The Role of Anomalous Data in Knowledge Acquisition: A Theoretical Framework and Implications for Science Instruction." *Review of Educational Research* Vol. 63: 1-49.
- Choi, B.S. and E. Gennaro. 1987. "The Effectiveness of Using Computer Simulated Experiments on Junior High Students' Understanding of the Volume Displacement Concept." *Journal of Research in Science Teaching* Vol. 24: 539-552.
- Clement, J. 1993. "Using Bridging Analogies and Anchoring Intuitions to Deal with Students' Preconceptions in Physics." *Journal of Research in Science Teaching* Vol. 30: 1241-1257.
- Cobb, P. 1994. "Where Is the Mind? Constructivist and Socio-Cultural Perspectives on Mathematical Development." *Educational Researcher* Vol. 23, No. 7: 13-20.
- Cognition and Technology Group at Vanderbilt. 1992. "Anchored Instruction in Science and Mathematics: Theoretical Basis, Developmental Projects, and Initial Research Findings." *Educational Researcher* Vol. 19, No. 6: 2-10.
- Cognition and Technology Group at Vanderbilt. 1993. "Anchored Instruction and Situated Cognition Revisited." *Educational Technology* Vol 33: 52-70.
- Dagher, Z.R. 1994. "Does the Use of Analogies Contribute to Conceptual Change?" *Science Education* Vol. 78: 601-614.
- Dagher, Z. and G. Cossman. 1992. "Verbal Explanations Given by Science Teachers: Their Nature and Implications." *Journal of Research in Science Teaching* Vol. 29: 361-374.
- Davis, J.O. 1977. "The Effects of Three Approaches to Science Instruction on the Science Achievement, Understanding, and Attitudes of Selected Fifth and Sixth Grade Students." *Dissertation Abstracts International* Vol. 39: 211A.
- Davison, M.A. 1989. *Use of the Learning Cycle to Promote Cognitive Development.* Doctoral dissertation, Purdue University, 1988. *Dissertation Abstracts International* Vol. 49: 3320-A.
- Dawson, G. 1991. *Science Vision: An Inquiry-based Videodisc Science Curriculum.* (ERIC Document Reproduction Service No. ED 336 257.)
- de Jong, T. and M.G.M. Ferguson-Hessler. 1986. "Cognitive Structures of Good and Poor Novice Problem Solvers in Physics." *Journal of Educational Psychology* Vol. 78: 279-288.
- diSessa, A.A. 1988. "Knowledge in Pieces." In *Constructivism in the Computer Age*, G. Forman and P.B. Pufal, editors. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Dreyfus, A., E. Jungwirth, and R. Eliovitch. 1990. "Applying the 'Cognitive Conflict' Strategy for Conceptual Change—Some Implications, Difficulties, and Problems." *Science Education* Vol. 74: 555-569.
- Duit, R. 1991a. "Students' Conceptual Frameworks: Consequences for Learning Science." In *The Psychology of Learning Science*, S.M. Glynn, R.H. Yeany, and B.K. Britton, editors (pp. 65-85). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
- Duit, R. 1991b. "On the Role of Analogies and Metaphors in Learning Science." *Science Education* Vol. 75: 649-672.
- Dupin, J.J. and S. Joshua. 1989. "Analogies and 'Modeling Analogies' in Teaching: Some Examples in Basic Electricity." *Science Education* Vol. 73: 207-224.
- Faryniarz, J.V. and L.G. Lockwood. 1992. "Effectiveness of Microcomputer Simulations in Stimulating Environmental Problem Solving by Community College Students." *Journal of Research in Science Teaching* Vol. 29: 453-470.
- Finegold, M. and R. Mass. 1985. "Differences in the Process of Solving Physics Problems Between Good Physics Problem Solvers and Poor Physics Problem Solvers." *Research in Science and Technological Education* Vol. 3: 59-67.
- Fisher, K. 1990. "Semantic Networking: The New Kid on the Block." *Journal of Research in Science Teaching* Vol. 27: 1001-1018.
- Flick, L. 1991. "Where Concepts Meet Precepts: Stimulating Analogical Thought in Children." *Science Education* Vol. 75: 215-230.
- Fowler, T.W. March 1975. *An Investigation of the Teacher Behavior of Wait Time During an Inquiry Science Lesson.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, Los Angeles, California.
- Frank, D.V. and J.D. Herron. April 1987. *Teaching Problem Solving to University General Students.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, Washington, DC.
- Friedel, A.W., D.L. Gabel, and J. Samuel. 1990. "Using Analogies for Chemistry Problem Solving: Does It Increase Understanding?" *School Science and Mathematics* Vol. 90: 674-682.
- Friedler, Y., R. Nachmias, and M.C. Linn. 1990. "Learning Scientific Reasoning Skills in Microcomputer-Based



- Laboratories." *Journal of Research in Science Teaching* Vol. 27: 173-191.
- Gabel, D.L. February 1981. *Facilitating Problem Solving in High School Chemistry*. Bloomington, IN: Indiana University, School of Education. (ERIC Document Reproduction Service No. ED 210 192.)
- Gabel, D.L., R.D. Sherwood, and L.G. Enochs. 1984. "Problem-Solving Skills of High School Chemistry Students." *Journal of Research in Science Teaching* Vol. 21: 221-233.
- Gabel, D.L. and K.V. Samuel. 1986. "High School Students' Ability to Solve Molarity Problems and Their Analog Counterparts." *Journal of Research in Science Teaching* Vol. 23: 165-176.
- Garigliano, L.J. 1972. *The Relation of Wait-Time to Student Behaviors in Science Curriculum Improvement Study Lessons*. Unpublished Doctoral Dissertation, Columbia University. (ERIC Document Reproduction Service No. ED 080 324.)
- Garnett, P.J. and D.F. Treagust. 1992. "Conceptual Difficulties Experienced by Senior High School Students of Electrochemistry: Electric Circuits and Oxidation-Reduction Equations." *Journal of Research in Science Teaching* Vol. 29: 121-142.
- Geban, O., P. Askar, and I. Ozkan. 1992. "Effects of Computer Simulations and Problem Solving Approaches on High School Students." *Journal of Educational Research* Vol. 86, No. 1: 5-10.
- Glasson, G. and R. Lalik. 1990. *Interpreting the Learning Cycle from a Language Learning Perspective*. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Atlanta, Georgia.
- Glynn, S.M. 1991. "Explaining Science Concepts: A Teaching-with-Analogies Model." In *The Psychology of Learning Science*, S. Glynn, R. Yearny, and B. Britton, editors (pp. 219-240). Hillsdale, NJ: Erlbaum.
- Gorodetsky, M. and R. Hoz. 1980. "Use of Concept Profile Analysis to Identify Difficulties in Solving Science Problems." *Science Education* Vol. 64: 671-678.
- Grayson, D. and L.C. McDermott. March 1989. *Using the Computer to Identify and Address Student Difficulties with Graphing*. Paper presented at the annual meeting of the American Educational Research Association, San Francisco.
- Griffiths, A.K., J. Pottle, and P. Whelan. April 1983. *Application of the Learning Hierarchy Model to the Identification of Specific Misconception for the Two Science Concepts*. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Dallas, Texas.
- Griffiths, A.K. and K.R. Preston. 1992. "Grade-12 Students' Misconceptions Relating to Fundamental Characteristics of Atoms and Molecules." *Journal of Research in Science Teaching* Vol. 29: 611-628.
- Hakerem, G., G. Dobrynina, and L. Shore. 1993. *The Effect of Interactive, Three Dimensional, High Speed Simulations on High School Science Students' Conceptions of the Molecular Structure of Water*. (ERIC Document Reproduction Service No. ED 362 390.)
- Harrison, A.G. and D.F. Treagust. 1993. "Teaching with Analogies: A Case Study in Grade-10 Optics." *Journal of Research in Science Teaching* Vol. 30: 1291-1307.
- Hart, E.P. and I.M. Robotom. 1990. "The Science-Technology-Society Movement in Science Education: A Critique of the Reform Process." *Journal of Research in Science Teaching* Vol. 27: 575-588.
- Hay, J.A. 1980. *Effects of Cooperative Goal Structuring on Sixth Grade Science Students' Abilities to Initiate Task and Maintenance Group Behaviors*. Doctoral dissertation, Michigan State University, 1980. *Dissertation Abstracts International* Vol. 41: 3857.
- Hegarty, M. 1991. "Knowledge and Processes in Mechanical Problem Solving." In *Complex Problem Solving: Principles and Mechanisms*, R.J. Sternberg and P.A. Frensch, editors (pp. 253-285). Hillsdale, NJ: Lawrence Erlbaum.
- Heller, J.I. and F. Reif. 1984. "Prescribing Effective Human Problem-Solving Processes: Problem Description in Physics." *Cognition and Instruction* Vol. 1: 177-216.
- Heller, P., R. Keith, and S. Anderson. 1992. "Teaching Problem Solving Through Cooperative Grouping. Part 1: Group Versus Individual Problem Solving." *American Journal of Physics* Vol. 60: 627-636.
- Heller, P. and M. Hollabaugh. 1992. "Teaching Problem Solving Through Cooperative Grouping. Part 2: Designing Problems and Structuring Groups." *American Journal of Physics* Vol. 60: 637-645.
- Herron, J.D. and T.J. Greenbowe. 1986. "What Can We Do About Sue: A Case Study of Competence." *Journal of Chemical Education* Vol. 63: 528-531.
- Hofmeister, A.M., S. Engelmann, and D. Carnine. 1988. *Developing and Validating Science Education Video-discs*. (ERIC Document Reproduction Service No. ED 297 943).
- Horton, P., A. McConney, M. Gallo, A. Woods, G. Senn, and D. Hamelin. 1993. "An Investigation of the Effectiveness of Concept Mapping as an Instructional Tool." *Science Education* Vol. 77: 95-111.
- Hoz, R., Y. Tomer, and P. Tamir. 1990. "The Relations Between Disciplinary and Pedagogical Knowledge and the Length of Teaching Experience of Biology and Geography Teachers." *Journal of Research in Science Teaching* Vol. 27: 973-988.
- Humphreys, B., R. Johnson, and D. Johnson. 1982. "Effects of Cooperative, Competitive, and Individualistic Learning on Students' Achievement in Science Class." *Journal of Research in Science Teaching* Vol. 19: 351-356.
- Jackman, L.E., W.P. Moellenberg, and G.D. Brabson. 1990. "Effects of Conceptual Systems and Instructional Methods on General Chemistry Laboratory Achievement." *Journal of Research in Science Teaching* Vol. 27: 699-709.
- Jackson, D.F., B.J. Edwards, and C.F. Berger. 1993. "Teaching the Design and Interpretation of Graphs Through Computer Aided Graphical Data Analysis." *Journal of Research in Science Teaching* Vol. 30: 483-501.
- Johnson, D.W. and R.T. Johnson. 1985a. "Classroom Conflict: Controversy Versus Debate in Learning Groups."



*American Educational Research Journal* Vol. 22: 237-256.

Johnson, R.T. and D.W. Johnson. 1985b. "Student-Student Interaction: Ignored but Powerful." *Journal of Teacher Education* Vol. 36, No. 4: 22-26.

Jones, R. and J. Steinbrink. 1989. "Using Cooperative Groups in Science Teaching." *School Science and Mathematics* Vol. 89: 541-551.

Jones, R. and J. Steinbrink. 1991. "Home Teams: Cooperative Learning in Elementary Science." *School Science and Mathematics* Vol. 91: 139-143.

Jungck, J. and J. Calley. 1986. *Genetics: Strategic Simulations in Mendelian Genetics*. Wentworth, NH: COMPRESS.

Kempa, R. and A. Ayob. 1991. "Learning Interactions in Group Work in Science." *International Journal of Science Education* Vol. 13: 341-354.

Kinnear, J. 1983. *Using Computer Simulations to Enhance Problem-Solving Skills and Concept Development in Biology Students*. Paper presented at the Computer ALITE Conference, Brisbane, Australia.

Kinzie, M.B., R. Strauss, and J. Foss. 1993. "The Effects of an Interactive Dissection Simulation on the Performance Achievement of High School Biology Students." *Proceedings of Selected Research and Development Presentations at the Convention of the Association for Educational Communications and Technology*. New Orleans, LA. (ERIC Document Reproduction Service No. ED 362 173.)

Krajcik, J.S. November 1989. "Students' Interactions with Science Software Containing Dynamic Visuals." In *Meanings of Science and Technology in Schools and Communities*, M. Eisenhart and J.G. Goetz (Chairs). Symposium conducted at the 88th annual meeting of the American Anthropological Association, Washington, DC.

Krajcik, J.S. and J.W. Layman. March 1989. *Middle School Teachers' Conceptions of Heat and Temperature: Personal and Teaching Knowledge*. Paper presented at the 62nd annual meeting of the National Association for Research in Science Teaching, San Francisco.

Kramers-Pals, H., J. Lambrechts, and P.J. Wolff. 1982. "Recurrent Difficulties: Solving Quantitative Problems." *Journal of Chemical Education* Vol. 59: 509-513.

Lake, J.H. 1973. *The Influence of Wait-Time on the Verbal Dimensions of Student Inquiry Behavior*. Unpublished doctoral dissertation, Rutgers University. (ERIC Document Reproduction Service No. ED 116 897.)

Larkin, J.H. 1980. "Skilled Problem Solving in Physics: A Hierarchical Planning Model." *Journal of Structural Learning* Vol. 1: 271-297.

Larkin, J.H. 1983. "The Role of Problem Representation in Physics." In *Mental Models*, D. Gentner and A.L. Stevens, editors (pp. 75-98). Hillsdale, NJ: Lawrence Erlbaum.

Larkin, J.H., J. McDermott, D.P. Simon, and H.A. Simon. 1980. "Models of Competence in Solving Physics Problems." *Cognitive Science* Vol. 4: 317-345.

Lavoie, D. April 1989. *Enhancing the Learning Cycle with Prediction and Level Three Interactive Videodisc Lessons in Science*. Paper presented at the annual meeting of the National Association for Research in Science Teaching, San Francisco.

Lavoie, D. March 1992. *The Effects of Adding a Prediction/Discussion Phase to a Science Learning Cycle*. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Boston.

Lawson, A.E. 1990. "Use of Reasoning to a Contradiction in Grades Three to College." *Journal of Research in Science Teaching* Vol. 27: 541-551.

Lawson, A.E. 1993. "The Importance of Analogy: A Prelude to the Special Issue." *Journal of Research in Science Teaching* Vol. 30: 1213-1214.

Lawson, A.E. and W.T. Wollman. 1976. "Encouraging the Transition from Concrete to Formal Cognitive Functioning—An Experiment." *Journal of Research in Science Teaching* Vol. 13: 413-430.

Lawson, A.E., M.R. Abraham, and J.W. Renner. 1989. *A Theory of Instruction: Using the Learning Cycle to Teach Science Concepts and Thinking Skills* (Monograph of the National Association for Research in Science Teaching, No. 1). Cincinnati, OH: NARST.

Lawson, A.E. and J. Weser. 1990. "The Rejection of Nonscientific Beliefs About Life: Effects of Instruction and Reasoning Skills." *Journal of Research in Science Teaching* Vol. 27: 589-606.

Lazarowitz, R. 1991. "Learning Biology Cooperatively: An Israeli Junior High School Study." *Cooperative Learning: The Magazine for Cooperating in Education* Vol. 11: 19-21.

Lazarowitz, R., J.H. Baird, R. Hertz-Lazarowitz, and J. Jenkins. 1985. "The Effects of Modified Jigsaw on Achievement, Classroom Social Climate, and Self-Esteem in High School Science Classes." In *Learning to Cooperate, Cooperating to Learn*, R. Slavin, S. Sharan, S. Kagan, R. Hertz-Lazarowitz, N.M. Webb, and R. Schmuck, editors (pp. 231-253). New York and London: Plenum.

Lazarowitz, R., R. Hertz-Lazarowitz, J.H. Baird, and V. Bowlden. 1988. "Academic Achievement and On-Task Behavior of High School Biology Students Instructed in a Cooperative Small Investigative Group." *Science Education* Vol. 72: 475-487.

Lazarowitz, R. and G. Karsenty. 1990. "Cooperative Learning and Students' Self-Esteem in Tenth Grade Biology Classrooms." In *Cooperative Learning, Theory and Research*, S. Sharan, editor (pp. 123-149). New York: Praeger.

Lazarowitz, R., R. Hertz-Lazarowitz, and J.H. Baird. 1994. "Learning Science in a Cooperative Setting: Academic Achievement and Affective Outcomes." *Journal of Research in Science Teaching* Vol. 31: 1121-1131.

Lehman, J. 1994. "Secondary Science Teachers' Use of Microcomputers During Instruction." *School Science and Mathematics* Vol. 94: 413-420.

Leonard, W.H. 1992. "A Comparison of Student Performance Following Instruction by Interactive Videodisc Versus Conventional Laboratory." *Journal of Research in Science Teaching* Vol. 29: 93-102.

Lesgold, A. and S. Lajoie. 1991. "Complex Problem Solving in Electronics." In *Complex Problem Solving: Principles*

02.75-18

- and Mechanisms, R.J. Sternberg and P.A. Frensch, editors (pp. 287-316). Hillsdale, NJ: Lawrence Erlbaum.
- Lewis, E.L. and M.C. Linn. April 1989. *Heat Energy and Temperature Concepts of Adolescents and Experts: Implications for Curricular Improvement*. Paper presented at the 62nd annual meeting of the National Association for Research in Science Teaching, San Francisco.
- Linn, M. 1988. *Autonomous Classroom Computer Environments for Learning*. Progress report and annotated bibliography. Washington, DC: National Science Foundation. (ERIC Document Reproduction Service No. ED 305 903).
- Linn, M.C. and N.B. Songer. April 1988. "Curriculum Reformulation: Incorporating Technology into Science Instruction." In *Conceptual Models of Science Learning and Science Instruction*. Symposium conducted at the annual meeting of the American Educational Research Association, New Orleans.
- Linn, M.C. and N.B. Songer. 1991. "Teaching Thermodynamics to Middle School Students: What Are Appropriate Cognitive Demands?" *Journal of Research in Science Teaching* Vol. 28: 885-918.
- Lockhart, R.S., M. Lamon, and M.L. Gick. 1988. "Conceptual Transfer in Simple Insight Problems." *Memory and Cognition* Vol. 16: 136-144.
- Lonning, R.A. 1993. "Effect of Cooperative Learning Strategies on Student Verbal Interactions and Achievement During Conceptual Change Instruction in 10th Grade General Science." *Journal of Research in Science Teaching* Vol. 30: 1087-1101.
- Lythcott, J. 1990. "Problem Solving and Requisite Knowledge of Chemistry." *Journal of Chemical Education* Vol. 67: 248-252.
- Marek, E. and S. Methven. 1991. "Effects of the Learning Cycle Upon Student and Classroom Teacher Performances." *Journal of Research in Science Teaching* Vol. 28: 41-53.
- McFadden, C.P. 1991. "Towards an STS School Curriculum." *Science Education* Vol. 75: 457-469.
- McKinnon, J.W. and J.W. Renner. 1971. "Are Colleges Concerned with Intellectual Development?" *American Journal of Physics* Vol. 39: 1047-1052.
- McMillan, C. and M. Swadener. 1991. "Novice Use of Qualitative Versus Quantitative Problem Solving in Electrostatics." *Journal of Research in Science Teaching* Vol. 28: 661-670.
- Mettes, C.T.C.W., A. Pilot, H.J. Roossink., and H. Kramers-Pals. 1980. "Teaching and Learning Problem Solving in Science." *Journal of Chemical Education* Vol. 57: 882-885.
- Meyers, R. 1993. *Interdisciplinary, Anchored Instruction Using Videotape*. Paper presented at the annual conference of the International Visual Literacy Association, Pittsburgh, PA. (ERIC Document Reproduction Service No. ED 363 306.)
- Mokros, J.R. and R.F. Tinker. 1987. "The Impact of Micro-computer-based Labs on Children's Ability to Interpret Graphs." *Journal of Research in Science Teaching* Vol. 24: 369-383.
- Myers, L.H. 1988. *Analysis of Student Outcomes in Ninth Grade Physical Science Taught with a Science/Technology/Society Focus Versus One Taught with a Textbook Orientation*. Unpublished doctoral dissertation, The University of Iowa.
- Nakhleh, M.B. and J.S. Krajcik. 1994. "Influence of Levels of Information as Presented by Different Technologies on Students' Understanding of Acid, Base, and pH Concepts." *Journal of Research in Science Teaching* Vol. 31: 1077-1096.
- National Research Council. November 1994. *National Science Education Standards*. Washington, DC: National Academy Press.
- National Science Teachers Association. 1982. *Science-Technology-Society: Science Education for the 1980's*. Position paper. Washington, DC: National Science Teachers Association.
- National Science Teachers Association. 1991. "Science/Technology/Society: A New Effort for Providing Appropriate Science for All (The NSTA Position Statement)." *NSTA Reports!* (April 1991): 36-37.
- National Science Teachers Association. 1993. *Scope, Sequence, and Coordination of Secondary School Science (Volume 1). The Content Core* (Revised edition). Washington, DC: National Science Teachers Association.
- Niaz, M. and W.R. Robinson. April 1989. *Teaching Algorithmic Problem Solving or Conceptual Understanding: Role of Developmental Level, Mental Capacity, and Cognitive Style*. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake Geneva, WI.
- Njoo, M. and T. de Jong. 1993. "Exploratory Learning with a Computer Simulation for Control Theory: Learning Processes and Instructional Support." *Journal of Research in Science Teaching* Vol. 30: 821-844.
- Novak, J.D. and D.B. Gowin. 1984. *Learning How to Learn*. New York: Cambridge University Press.
- Novak, J.D. and D. Musonda. 1991. "A Twelve-Year Longitudinal Study of Science Concept Learning." *American Educational Research Journal* Vol. 28: 117-153.
- Okebukola, P.A. 1985a. "Effects of Student-Student Interactions on Affective Outcomes of Science Instruction." *Research in Science and Technological Education* Vol. 3, No. 1: 5-17.
- Okebukola, P.A. 1985b. "The Relative Effectiveness of Cooperative and Competitive Interaction Techniques in Strengthening Students' Performance in Science Classrooms." *Science Education* Vol. 69: 501-511.
- Okebukola, P.A. 1986a. "Cooperative Learning and Students Attitudes to Laboratory Work." *School Science and Mathematics* Vol. 86: 582-590.
- Okebukola, P.A. 1986b. "The Influence of Preferred Learning Styles on Cooperative Learning in Science." *Science Education* Vol. 70: 509-518.
- Okebukola, P.A. 1986c. "Impact of Extended Cooperative and Competitive Relationships on the Performance of Students in Science." *Human Relations* Vol. 39: 673-682.
- Okebukola, P.A. and M.B. Ogunniyi. 1984. "Cooperative, Competitive and Individualistic Laboratory Interaction

- Patterns: Effects on Students' Performance and Acquisition of Practical Skills." *Journal of Research in Science Teaching* Vol. 21: 875-884.
- Pankratius, W.J. 1990. "Building an Organized Knowledge Base: Concept Mapping and Achievement in Secondary School Physics." *Journal of Research in Science Teaching* Vol. 27: 315-333.
- Polya, G. 1945. *How to Solve It*. Garden City, NY: Doubleday.
- Purser, R.K. and J.W. Renner. 1983. "Results of Two Tenth-Grade Teaching Procedures." *Science Education* Vol. 67: 85-98.
- Ramsden, J. 1992. "If This Is Enjoyable, Is It Science?" *School Science Review* Vol. 73, No. 265: 65-71.
- Ramsden, J. 1994. "Context and Activity-Based Science in Action: Some Teachers' Views of the Effects on Pupils." *School Science Review* Vol. 75, No. 272: 7-14.
- Reif, F. 1983. "How Can Chemists Teach Problem Solving?" *Journal of Chemical Education* Vol. 60: 948-953.
- Reif, F. and J.I. Heller. 1982. "Knowledge Structures and Problem Solving in Physics." *Educational Psychologist* Vol. 17, No. 2: 102-127.
- Renner, J., M. Abraham, and H.H. Birnie. 1985. "The Importance of the Form of Student Acquisition of Data in Physics Learning Cycles." *Journal of Research in Science Teaching* Vol. 22: 303-325.
- Renner, J., and E. Marek. 1988. *The Learning Cycle and Elementary School Science Teaching*. Portsmouth, NH: Heinemann.
- Riley, J.P., II. 1986. "The Effects of Teachers' Wait-Time and Knowledge Comprehension Questioning on Pupil Science Achievement." *Journal of Research in Science Teaching* Vol. 23: 335-342.
- Rivers, R. and E. Vockell. 1987. "Computer Simulations to Stimulate Scientific Problem Solving." *Journal of Research in Science Teaching* Vol. 30: 153-173.
- Robertson, W.C. 1990. "Detection of Cognitive Structure with Protocol Data: Predicting Performance on Physics Transfer Problems." *Cognitive Science* Vol. 14: 253-280.
- Rogg, S.R. and J.B. Kahle. March 1992. *The Characterization of Small Instructional Work Groups in Ninth-Grade Biology*. Paper presented at the 65th annual meeting of the National Association for Research in Science Teaching (Narst), Boston.
- Rosenthal, D.B. 1989. "Two Approaches to STS Education." *Science Education* Vol. 73: 581-589.
- Roth, W. 1994. "Student Views of Collaborative Concept Mapping: An Emancipatory Research Project." *Science Education* Vol. 78: 1-34.
- Roth, W. and A. Roychoudhury. 1992. "The Social Construction of Scientific Concepts or the Concept Map as Conscriptive Device and Tool for Social Thinking in High School Science." *Science Education* Vol. 76: 531-557.
- Rowe, M.B. 1974a. "Wait-Time and Rewards as Instructional Variables, Their Influence on Language, Logic, and Fate Control: Part I, Fate Control." *Journal of Research in Science Teaching* Vol. 11: 81-94.
- Rowe, M.B. 1974b. "Relation of Wait-Time and Rewards to the Development of Language, Logic, and Fate Control: Part II, Rewards." *Journal of Research in Science Teaching* Vol. 11: 291-308.
- Rowe, M.B. 1986. "Wait Time: Slowing Down May Be Way of Speeding Up." *Journal of Teacher Education* Vol. 37: 43-50.
- Rubba, P.A., M. McGuyer, and T.M. Wahlund. 1991. "The Effects of Infusing STS Vignettes into the Genetics Unit of Biology on Learner Outcomes in STA and Genetics: A Report of Two Investigations." *Journal of Research in Science Education* Vol. 28: 537-552.
- Rubin, R.L. and J.T. Norman. March/April 1989. *A Comparison of the Effect of a Systematic Modeling Approach and the Learning Cycle Approach on the Achievement of Integrated Science Process Skills of Urban Middle School Students*. Paper presented at the annual meeting of the National Association for Research in Science Teaching, San Francisco. (ERIC Document Reproduction Service No. Ed 308 838.)
- Rubin, R.L. and J.T. Norman. 1992. "Systematic Modeling Versus the Learning Cycle: Comparative Effects on Integrating Science Process Skill Achievement." *Journal of Research in Science Teaching* Vol. 29: 715-727.
- Samiroden, W.D. 1983. *The Effects of Higher Cognitive Level Questions Wait Time Ranges by Biology Student Teachers on Student Achievement and Perception of Teacher Effectiveness*. Unpublished doctoral dissertation, Oregon State University.
- Savenye, W.C. and E. Strand. 1989. *Teaching Science Using Interactive Videodisc: Results of the Pilot Year Evaluation of the Texas Learning Technology Group Project*. Proceedings of selected research papers presented at the annual meeting of the Association for Educational Communications and Technology. Dallas, TX. (ERIC Document Reproduction Service No. Ed 308 838).
- Scharmann, L. March 1992. *Teaching Evolution: The Influence of Peer Instructional Modeling*. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Boston.
- Schmidt, H. 1990. "Secondary School Students' Strategies in Stoichiometry." *International Journal of Science Education* Vol. 12: 457-471.
- Schneider, L.S. and J.W. Renner. 1980. "Concrete and Formal Teaching." *Journal of Research in Science Teaching* Vol. 17: 503-517.
- Schoenfeld, A.H. 1978. "Can Heuristics Be Taught?" In *Cognitive Process Instruction*, J. Lochhead and J.J. Clement, editors (pp. 315-338). Philadelphia: Franklin Institute Press.
- Sherman, L.W. 1989. "A Comparative Study of Cooperative and Competitive Achievement in Two Secondary Biology Classrooms: The Group Investigative Model Versus an Individually Competitive Goal Structure." *Journal of Research in Science Teaching* Vol. 26: 55-64.
- Simmons, P.E. 1989. *Problem Solving Strategies and Approaches of Successful and Unsuccessful Subjects Interacting with a Genetics Computer Simulation*. Paper presented at the annual meeting of the National Association of Research in Science Teaching, San Francisco.
- Slavin, R.E. 1980. "Cooperative Learning." *Review of Education Research* Vol. 50: 315-342.



- Slavin, R.E. 1984. "Students Motivating Students to Excel: Cooperative Incentives, Cooperative Tasks, and Student Achievement." *The Elementary School Journal* Vol. 85: 53-63.
- Slavin, R.E. 1991. "Synthesis of Research on Cooperative Learning." *Educational Leadership* Vol. 48, No. 5: 71-82.
- Smith, S.G. and L.L. Jones. 1988. "Images, Imagination, and Chemical Reality." *Journal of Chemical Education* Vol. 66, No. 1: 8-11.
- Starr, M. and J. Krajcik. 1990. "Concept Maps as a Heuristic for Science Curriculum Development: Toward Improvement in Process and Product." *Journal of Research in Science Teaching* Vol. 27: 987-1000.
- Stavy, R. 1991. "Analogy to Overcome Misconceptions About Conservation of Matter." *Journal of Research in Science Teaching* Vol. 28: 305-313.
- Stavy, R. and D. Tirosh. 1993. "When Analogy Is Perceived as Such." *Journal of Research in Science Teaching* Vol. 30: 1229-1239.
- Stiff, L.V. 1988. "Problem Solving by Example." *School Science and Mathematics* Vol. 88: 666-675.
- Sumfleth, E. 1988. "Knowledge of Terms and Problem-Solving in Chemistry." *International Journal of Science Education* Vol. 10: 45-60.
- Sutman, F.X. and M.H. Bruce. 1992. "Chemistry in the Community: A Five Year Evaluation." *Journal of Chemical Education* Vol. 69: 564-567.
- Sutula, V. and J.S. Krajcik. September 1988. *The Effective Use of Analogies for Solving Mole Problems in High School Chemistry*. Paper presented at the annual meeting of the National Association of Research in Science Teaching, Lake Ozark, MO.
- Sweller, J. 1988. "Cognitive Load During Problem Solving: Effects on Learning." *Cognitive Science* Vol. 12: 257-285.
- Thagard, P. 1992. "Analogy, Explanation, and Education." *Journal of Research in Science Teaching* Vol. 29: 537-544.
- Thiele, R.B. and D.F. Treagust. 1994. "An Interpretive Examination of High School Chemistry and Teachers' Analogical Explanations." *Journal of Research in Science Teaching* Vol. 31: 227-242.
- Tingle, J.B. and R. Good. 1990. "Effects of Cooperative Grouping on Stoichiometric Problem Solving in High School Chemistry." *Journal of Research in Science Teaching* Vol. 27: 671-683.
- Tinker, R.F. 1985. "How to Turn Your Computer into a Science Lab." *Classroom Computer Learning* Vol. 5, No. 6: 26-29.
- Tobin, K.G. 1985. "The Effect of an Extended Teacher Wait Time on Science Achievement." *Journal of Research in Science Teaching* Vol. 17: 469-475.
- Tobin, K.G. 1986. "Effects of Teacher Wait Time on Discourse Characteristics in Mathematics and Language Arts Classes." *American Educational Research Journal* Vol. 32: 191-200.
- Tobin, K.G. 1987. "The Role of Wait Time on Higher Level Cognitive Learning." *Review of Educational Research* Vol. 57: 69-95.
- Tobin, K.G. and W. Capie. 1982. "Relationships Between Classroom Process Variables and Middle School Science Achievement." *Journal of Educational Psychology* Vol. 14: 441-454.
- Treagust, D.F., R. Duit, P. Joslin, and I. Lindauer. 1992. "Science Teachers' Use of Analogies: Observations from Classroom Practice." *International Journal of Science Education* Vol. 14: 413-422.
- Van Heuvelen, A. 1991. "Overview, Case Study Physics." *American Journal of Physics* Vol. 59: 898-906.
- Waks, L.J. and B.A. Barchi. 1992. "STS in U.S. School Science: Perceptions of Selected Leaders and Their Implications for STS Education." *Science Education* Vol. 76: 79-90.
- Wallace, J. and J. Mintzes. 1990. "The Concept Map as a Research Tool: Exploring Conceptual Change in Biology." *Journal of Research in Science Education* Vol. 27: 1033-1052.
- Walters, J. 1988. "Teaching Biological Systems." *Journal of Biological Education* Vol. 22: 87.
- Ward, C.R. and J.D. Herron. 1980. "Helping Students Understand Formal Chemical Concepts." *Journal of Research in Science Teaching* Vol. 17: 387-400.
- Ward, M. and J. Sweller. 1990. "Structuring Effective Worked Examples." *Cognition and Instruction* Vol. 7: 1-39.
- Watson, S.B. 1991. "Cooperative Learning and Group Educational Modules: Effects on Cognitive Achievement of High School Biology Students." *Journal of Research in Science Teaching* Vol. 28: 141-146.
- Webb, N. 1985. "Student Interaction and Learning in Small Groups: A Research Summary." In *Learning to Cooperate, Cooperating to Learn*, R. Slavin, S. Sharan, K. Spencer, R. Lazarowitz, C. Webb, and R. Schmuck, editors. Leeds: The University of Leeds.
- Wells, G. and C. Berger. 1986. "Teacher/Student-Developed Spreadsheet Simulations: A Population Growth Example." *Journal of Computers in Mathematics and Science Teaching* Vol. 42: 34-40.
- Westbrook, S.L., L.N. Rogers, and E.A. Marek. April 1990. *An Analysis of the Relationships of Formal Reasoning, Science Process Skills, Gender, and Instructional Treatment to Conceptual Shifts in Tenth Grade Biology Students*. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Atlanta, GA.
- White, B.Y. and J.R. Frederickson. 1989. *Designing Articulate Microworlds that Facilitate Learning, Understanding, and Problem Solving in Science Education*. American Educational Research Association: San Francisco.
- White, B.Y. and P. Horowitz. 1987. *Thinkertools: Enabling Children to Understand Physical Laws*. Report No. 6470. Cambridge, MA: BBN Laboratories.
- White, B.Y. and P. Horowitz. 1988. "Computer Microworlds and Conceptual Change: A New Approach to Science Education." In *Improving Learning: New Perspectives*, P. Ransden, editor (pp. 69-80). London: Kegan Paul.
- Willerman, M. and R.A. Mac Harg. 1991. "The Concept Map as an Advance Organizer." *Journal of Research in Science Teaching* Vol. 28: 705-711.



- Williamson, V.M. and M.R. Abraham. 1995. "The Effects of Computer Animation on the Particulate Mental Models of College Chemistry Students." *Journal of Research in Science Teaching*.
- Wilson, J.M. 1994. "Network Representations of Knowledge About Chemical Equilibrium: Variations with Achievement." *Journal of Research in Science Education* Vol. 31: 1133-1147.
- Winther, A.A. and T.L. Volk. 1994. "Comparing Achievement of Inner-City High School Students in Traditional Versus STS-Based Chemistry Courses." *Journal of Chemical Education* Vol. 71: 501-505.
- Wise, K.C. 1988. "The Effects of Using Computing Technologies in Science Instruction: A Synthesis of Classroom-Based Research." In *1988 AETSs Yearbook*, J.D. Ellis, editor (pp. 105-118). Columbus: The Ohio State University.
- Wiser, M. and D. Kipman. April 1988. *The Differentiation of Heat and Temperature: An Evaluation of the Effect of Microcomputer Models on Students' Misconceptions*. Paper presented at the annual meeting of the American Educational Research Association, New Orleans.
- Wong, D.E. 1993a. "Self-Generated Analogies as a Tool for Constructing and Evaluating Explanations of Scientific Phenomena." *Journal of Research in Science Teaching* Vol. 30: 367-380.
- Wong, D.E. 1993b. "Understanding the Generative Capacity of Analogies as a Tool for Explanation." *Journal of Research in Science Teaching* Vol. 30: 1259-1272.
- Wright, D.S. and C.D. Williams. 1986. "A Wise Strategy for Introductory Physics." *Physics Teacher* Vol. 24: 211-216.
- Yager, R.E. and P. Tamir. 1993. "STS Approach: Reasons, Intentions, Accomplishments, and Outcomes." *Science Education* Vol. 77: 637-658.
- Yager, R.E., P. Tamir, and N. Mackinnu. 1993. "The Effect of a Science/Technology/Society Approach on Achievement and Attitudes of Students Enrolled in Science Classes in Grades 4 Through 9." Manuscript submitted for publication.
- Yager, R.E. and S.O. Yager. 1985. "Changes in Perceptions of Science for Third, Seventh, and Eleventh Grade Students." *Journal of Research in Science Teaching* Vol. 22: 347-358.
- Zeitoun, H.H. 1984. "Teaching Scientific Analogies: a Proposed Model." *Research in Science and Technological Education* Vol. 2: 107-125.
- Zietsman, A.I. and P.W. Hewson. 1986. "Effect of Instruction Using Microcomputer Simulations and Conceptual Change Strategies on Science Learning." *Journal of Research in Science Teaching* Vol. 23: 27-39.
- Zoller, U., J. Ebenezer, K. Morely, S. Paras, V. Sandberg, C. West, T. Wolthers, and S.H. Tan. 1990. "Goal Attainment in Science-Technology-Society S/T/S Education and Reality: The Case of British Columbia." *Science Education* Vol. 74: 19-36.