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RESEARCH-BASED STRATEGIES FOR IMPROVING STUDENT ACHIEVEMENT: SCIENCE

At A Glance

A review of general, research-based teaching strategies and practices in science is provided, based on ERS' *Handbook of Research on Improving Student Achievement*. Earlier information capsules summarized research-based strategies that have been successfully implemented in language arts (reading and writing) and mathematics. ERS' full report presents effective practices for improving student learning in all of the major elementary and secondary subject areas. The strategies contained in ERS' report were developed to help educators use accurate, comprehensive research in their instructional practices.

Educational Research Service (ERS) has published a report designed to promote research-based decision making in schools. The report, entitled *Handbook of Research on Improving Student Achievement*, provides research findings and classroom implications for each of the major disciplines taught in elementary and secondary schools. Scholars who contributed to the handbook conducted extensive searches of the literature, evaluated the quality of the research, and prepared the syntheses that are included in the handbook. The handbook contains a combination of emerging strategies and "tried and true" practices. By offering comprehensive, research-based strategies for use in the classroom, the handbook can assist educators in the selection and implementation of effective instructional practices. Although research cannot identify the best way to teach in every classroom, it can point to the instructional practices that are most likely to achieve the desired results.

This information capsule is the third and final in a series that summarizes research-based teaching strategies in reading and writing, mathematics, and science. Effective practices for improving student learning in all of the major elementary and secondary subject areas can be found in ERS' handbook. Following are strategies and practices that have been successfully implemented in science.

Learning Cycle Approach. Research has shown that use of the learning cycle approach (exploration, invention, and application) results in higher content achievement, improved thinking skills, and more positive attitudes toward science. The exploration phase allows students to raise questions about the phenomena being studied. In the invention phase, terms and concepts are introduced to explain the patterns discovered in the exploration phase. The application phase gives students the opportunity to apply these concepts to new situations. Teachers should emphasize all three phases of the learning cycle. Laboratory instruction (exploration and application) without concept introduction (invention) has not been found to increase student achievement in science. There is evidence that modifications to the learning cycle can increase its effectiveness as a learning strategy. For example, teachers can add an engagement, prediction, or discussion phase to the exploration phase or follow the application phase with an evaluation component.

Collaborative Learning. Studies have found that using collaborative learning for classroom and laboratory instruction improves students' attitudes towards laboratory work and increases their achievement, long-term retention, and on-task behavior. Two types of collaborative learning are frequently used for the teaching of science:

- **Jigsaw approach.** Each student in the group is assigned part of a larger task. Students with the same role from each jigsaw group in the class form new groups in which members share ideas and perform tasks. They then return to their original group, where they are responsible for teaching students the new information.
- **Laboratory, investigative approach.** Each student assumes a different role, such as recorder, facilitator, or experimenter. Roles rotate with each laboratory assignment. Studies have found that this approach fosters positive interdependence, face-to-face interaction, individual accountability, interpersonal and small-group interaction, and group processing.

Recent studies have found that collaborative learning is most effective when students are encouraged to cooperate within their group but to compete with other groups within the class. Studies have also found that, when roles are not assigned, students assume roles based on their expertise. This learning method has been shown to enhance both problem solving ability and concept development.

Analogies. Research shows that using analogies in science instruction increases students' conceptual understanding by allowing them to compare the familiar with the unfamiliar. Analogies motivate students to learn by stimulating their interest. Analogies can be simple or complex; however, use of complex analogies is more appropriate at the secondary level, where students have developed the appropriate reasoning skills. A considerable amount of classroom time should be devoted to discussing the analogies. Discussion helps students construct their own knowledge and allows teachers to base instruction on students' prior knowledge. Asking students to create their own analogies also appears to be an effective instructional strategy.

Wait Time. In most classrooms, students are typically given less than one second to respond to questions asked by their teachers. Research shows that, under these circumstances, students tend to give short, recall responses or no responses at all rather than give answers that involve higher-level thinking. When teachers pause between three and seven seconds after asking higher-level questions, achievement on higher-level science tests increases significantly. Increasing wait time also results in increases in the length of student responses, the number of unsolicited responses, the number of speculative responses, and the number of responses from less capable students. These findings are consistent across all grade levels and science disciplines. The optimal wait time for a given question should be adjusted to the cognitive level of the question.

Concept Mapping. The term concept mapping refers to the strategy used to design concept maps. A concept map is a form of web diagram, used for exploring knowledge and gathering and sharing information. Maps consist of cells that contain concepts arranged in hierarchical order. Links explain the relationships between the cells and arrows describe the direction of the relationships. Concept mapping in the science classroom, especially for biology instruction, increases science achievement and improves students' attitudes. Although studies have found no differences in science achievement when maps are designed by the teacher or by students, greater gains in achievement have been reported when students supply the key terms used to construct the maps. Concept maps can be used as an overview at the beginning of a unit, during instruction to assess conceptual understanding, and at the end of a unit to evaluate learning. Studies have reported the greatest benefits, however, when maps are used at the end of a unit. Concept maps can also be used by teachers as an aid to learning, discovery, and problem solving in curriculum development.

Computer Simulations. Studies show that students' conceptual understanding, process skills, and problem solving abilities can be improved when computer simulation software is used to represent real-world situations. Many scientific models are difficult or impossible to observe or are so complex they're hard to study in the laboratory (for example, genetics or the motion of atoms). Computer simulations can overcome these obstacles. Simulations can be used in the classroom, but they have been found to be most effective when used by students alone or in small groups. Computer simulations should not be used exclusively in place of laboratory activities and teachers should help students identify the limitations of the simulated models.

Microcomputer-Based Laboratories (MBLs). In MBLs, students use electronic probes that are interfaced with a microcomputer that directly records and graphs the data they are collecting. This enables students to immediately see trends in the data as they're being collected. By using MBLs, students can examine phenomena not accessible through standard laboratory experiences. Although a limited number of studies have been conducted on the use of MBLs, the results indicate that MBLs may foster secondary level students' scientific understanding. Research also shows that students who use MBLs are better able to interpret graphs, while students who participate in conventional laboratory experiences are better able to construct graphs. Since both skills are important instructional outcomes, science instruction should combine MBLs and conventional laboratory experiences.

Systematic Approaches in Problem Solving. Studies have found that planning solutions to mathematical chemistry and physics problems in a systematic way helps students solve these problems correctly. Students use different strategies when solving mathematical problems, but novice problem solvers can improve their skills if they solve problems in an organized way. Research suggests a four-step approach to mathematical problem solving in the sciences: understanding the problem, devising a plan, carrying out the plan, and looking back. Students should identify what information is provided in the problem and what information is being sought. Once the problem is understood, students can use this information to formulate plans for the solution. After they have solved the problem, students must check their math, their execution of the plan, and the reasonableness of their answer.

The four steps do not always occur sequentially. For example, when devising a plan, students may need to return to the understanding phase to recall additional information. The steps don't come naturally to students and must be practiced as students are taught to solve problems. Since using a systematic approach requires more time than using a formula, teachers should assign students fewer, but more varied, problems and provide them with more time for problem solving.

Conceptual Understanding in Problem Solving. Research at the secondary and postsecondary levels indicates that many students lack an understanding of the basic concepts needed to solve science problems. Students' use of algorithms to solve science problems doesn't necessarily lead to conceptual understanding. Even when students solve problems correctly, they are often unable to answer the conceptual questions upon which the problems are based, such as explaining the meaning of what they've done or describing the variables and the relationship between the variables involved. Recent studies show that understanding the basic concepts qualitatively helps students solve quantitative problems in biology, physics, and chemistry. Teachers should first emphasize a qualitative understanding of the underlying concepts. Mathematical problem solving can then provide students with deeper insight into the scientific concepts.

Science-Technology-Society (STS). STS approaches can be used to make science more relevant to students' lives. These approaches teach science concepts and principles so students develop an appreciation of the interactive nature of science, technology, and society. Students also gain knowledge of the technological applications of science and develop the ability to respond critically to technological issues. The use of STS approaches has been found to improve students' creativity and attitudes toward science and increase the number of students taking additional science courses and advanced level science courses.

STS issues can be included as a small part of the curriculum, but recent studies confirm that a more effective approach is to integrate the STS approach fully into the curriculum. When the STS approach is integrated into the curriculum, researchers have found an increase in students' understanding of the processes of science, including analyzing experimental data, designing and testing the validity of proposed explanations, communicating experimental results, and using these results as evidence for their explanations.

Real-Life Situations. Research supports the use of real-life situations in science instruction through actual observation or technological simulations to increase students' overall achievement and interest in science and to improve their problem solving skills. Students frequently compartmentalize learning. Problem solving and learning must take place in real-world contexts so students recognize that the topics they're studying apply to real-life situations. Teachers can utilize films, videos, and CD-ROMs to depict real-life situations or simulations of real-life situations. Interactive technology, in which students are required to make decisions about their own learning, can be an effective substitute for conventional laboratory experiences.

Discrepant Events. Discrepant events are a form of anomalous or irregular data that help students focus on their prior beliefs. Using discrepant events in science instruction is a strategy that can change students' beliefs and move them closer to accepted scientific views. Studies have found that the use of discrepant events in science instruction leads to cognitive conflict that increases students' conceptual understanding and improves their attitudes toward critical thinking activities. Discrepant events can be illustrated through demonstrations, hands-on activities, computer simulations, or videotapes. An example of a demonstration of a discrepant event in physics is to drop a styrofoam ball and a steel ball of equal volumes from the same height at the same time and observe that both balls hit the floor at the same time. Because most students think the heavier ball will hit first, the event is discrepant. Research on the effective use of discrepant events suggests that teachers shouldn't confirm or deny students' tentative explanations of the event, but instead provide guidance so they can arrive at explanations on their own.

Summary

A review of general, research-based teaching strategies and practices in science has been provided, based on ERS' *Handbook of Research on Improving Student Achievement*. Earlier information capsules summarized research-based strategies that have been successfully implemented in language arts (reading and writing) and mathematics. ERS' full report presents effective practices for improving student learning in all of the major elementary and secondary subject areas. The strategies contained in ERS' report were developed to help educators use accurate, comprehensive research in their instructional practices.

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