Research Within Reach: Science Education

A Research-Guided Response to the Concerns of Educators

Does research tell us anything about the effects of various instructional strategies on student achievement?

In this chapter, the generic term "instructional strategies" will be used to cover instructional strategies, teaching techniques, and methods. One may view instructional strategies as a limited aspect of a more complex teaching plan that describes either the teacher's or student's role in the instructional process. By contrast, an instructional system is a general plan, encompassing many aspects, for conducting a course over an extended period of time. In this chapter, we will discuss instructional strategies and then consider instructional systems. We will conclude with implications for an effective science classroom.

Instructional strategies may be classified in a number of ways (16). Strategies in which the teacher has direct control are referred to as "teacher-centered." Common examples include lectures, demonstrations, teacher-led discussions, and questioning. "Student-centered" strategies allow students to play a more active or self-guided role. Common examples are laboratory activities, use of learning activity packets, and student-planned activities. Instructional strategies may also be classified as "direct" or "deductive," or as "indirect" or "inductive," each encompassing both aspects of student and teacher-centered instruction. The use of direct strategies implies that science is being communicated by the teacher to the student. The teacher is in control. Indirect strategies suggest the teacher plays the role of facilitator, guide, or catalyst. Science is being communicated through the materials to the student. The use of different strategies may require shifting role relationships and responsibilities for both teachers and students.

Research on the quality of instruction is extensive, diverse, complicated, and often appears to be inconclusive. Reviews of hundreds of studies have resulted in disappointment on the part of many reviewers who perceive a lack of substantive research in the quality of instruction and its influence on student learning (18). Often, attempts at research synthesis, based on the qualitative character of the research, give rise to differing views on the summative findings in a given research area. Long narratives citing study after study provide little basis for objective comparison and accumulation of results. If study characteristics and outcomes could be quantified, research synthesis might gain a new precision and objectivity, providing a finer measure of what is known, as well as giving a better picture of the gaps and flaws in the accumulated research (4).

A technique that allows quantitative synthesis of a large number of research studies is meta-analysis (9, 10). Meta-analysis is proving useful in translating the results of numerous studies on a particular topic into a concise form that is understandable to those who may be in a position to apply the results. (For a fuller discussion of meta-analysis, see Chapter 1.)

From the results of recent meta-analyses of instructional strategies, some clear directions can be indicated for constructing a working model of effective classroom practices. The first major meta-analysis of instructional strategies was conducted by Boulanger (4). The purpose of his study was to synthesize quantitatively the published science education research conducted during 1963-1978 with students in the 6th through 12th grades. Through a simple count of independent variables (instructional strategies), he identified from fifty-one studies six instructional clusters that related to cognitive outcomes.

The instructional cluster that produced the most significant gains in improving student conceptual learning was the use of preinstructional strategies such as behavioral objectives, advanced organizers, or set induction. These studies compared the effects of using a preinstructional strategy with a comparable instructional treatment, where no preinstructional strategy or placebo was used.

Preinstructional strategies may take any of several forms. A teacher may communicate the behavioral objectives to the class prior to beginning instruction. Set induction strategies prepare students for learning by directing or focusing attention on what is to be presented or learned, by frequently motivating students to attend to the lesson, and by encouraging students to become interested. Set induction strategies may take the form of questions that interest the student and can be answered later in the lesson. Advanced organizers allows the teacher to relate what is to be learned to what is already known. For example, this might be done by comparing the circulatory system to a hot water system prior to a presentation on the circulation of the blood. Advanced organizers relate the unfamiliar to the familiar. Use of any or all of these preinstructional strategies can improve student conceptual learning, especially when used with other instructional activities by classroom teachers.

Boulanger also found that greater realism or concreteness of supporting instructional materials was associated with greater cognitive achievement. Instructional materials may be placed on a continuum from concrete to symbolic: manipulatives are more concrete than are pictorial stimuli, which, in turn, are more concrete than printed text material. Similarly a student's lab experiment is more concrete than is a teacher's demonstration, and the teacher demonstration is more concrete than a lecture. All the studies Boulanger looked at showed that greater realism or concretness in supporting instructional materials led to greater cognitive achievement. When given a choice, those teachers who utilize manipulatives, pictorial stimuli, or hands-on experiences in appropriate instructional situations will be more effective in producing cognitive achievement.

A second large meta-analysis was conducted by Wise and Okey as part of the University of Colorado Science Meta-Analysis Project (21). The purpose of this study was to synthesize findings concerning the effects of various teaching strategies on science achievement. Through analysis of 160 studies, twelve categories of teaching techniques or instructional strategies were identified. All the categories represented a variety of means researchers have used to bolster science achievement by altering one or more aspects of the instruction situation.

The average impact of the teaching strategies analyzed in this report was an increase in achievement of about one-third of a standard deviation, or 13 percentile points. The most pertinent categories (those greater than one-third standard deviations) will be discussed here to identify their contribution to an emerging effective science classroom.

The most significant category identified is wait-time. Wait-time occurs when a teacher pauses from three to five seconds after asking a question and again after the student response is given. When teachers employ wait-time, researchers have found the length of student responses increases, the failure to respond decreases, the incidence of speculative thinking increases, student-to-student interactions increase, and more questions are asked by students. Wise and Okey found that use of wait-time strategies increases cognitive outcomes, critical thinking, creatively logical thinking, and affective measures by .90 standard deviations (21).

Another category of instructional strategies that proved highly significant was the use of focusing techniques. Focusing occurs when students are alerted to the objectives or intent of instruction before, during, or after instruction. General examples include providing students with objectives, reinforcing objectives at various points during instruction, or using advanced organizers. Focusing strategies help students focus their attention on what is to be learned, much the same as the preinstructional strategies discussed earlier.

Another category Wise and Okey created is one that corresponds to Boulanger's cluster of realism or concreteness. Wise and Okey refer to this as manipulation. Manipulative activities require students to handle, operate, or in some way work or practice with physical objects as part of the instructional process. Being involved with concrete manipulatives is much more effective in producing large effects in achievement than having students observe someone else performing an experiment, or merely reading about it.

Wise and Okey reported a number of other categories in which large effects in science achievement were shown (21). In all cases, teachers had altered some aspect of the instructional situation. For example, by modifying or revising instructional materials, teachers contributed to increased achievement. Materials were rewritten for a specific reading level or were annotated. Directions were presented orally, pictorially, or by audiotape.

Another attempt to alter the instructional process was through the use of questioning strategies to improve achievement. By varying the levels of questions asked or the positions of questions asked during instruction, teachers can help increase student achievement. For instance, attempts might be made to ask more questions requiring comprehension, application, or analysis skills instead of relying on knowledge-level questions. Or, teachers may ask questions during films, or before, during, or after assigned reading. The use of questioning strategies represents a deliberate attempt on the part of the teacher to involve students in the instructional process and helps call the students' attention to significant facts or concepts.

Another category of effective strategies related to using tests to improve achievement. Usually this involved a change in the frequency of testing, the purpose of testing, or the level of test items. Examples of effective use of tests include formative testing, immediate or explanatory feedback, diagnositic testing and remediation, optional testing, and testing to mastery.

Two categories produced smaller achievement effects (around one-third standard deviations). The inquiry-discovery category included teaching techniques that were more student-centered and less step-by-step teacher-directed learning experiences. When teachers utilized inquiry lessons, guided discoveries, or inductive laboratories, improvements in achievement were noted. A similar category called "teacher-direction" included variations in the extent to which the learning task was spelled out for the student. Examples include situations in which students conduct experiments or activities given only sketchy direction, or when students select specific objectives and assume responsibility for learning those objectives.

What is important about the results reported by Wise and Okey is that a deliberate attempt was made by teachers to alter some aspect of the instructional environment to produce gains in achievement. The categories discussed above have resulted in successful teaching and learning.

The Wise and Okey study offers support for other recent research reviews that have concluded that direct teaching strategies have greater impact than indirect ones (14). The large effect sizes of wait-time and focusing are related to direct instructional strategies. The relatively smaller effect sizes of inquiry-discovery and teacher direction are related to indirect instruction.

While the results of these two meta-analyses are not definitive and specific toward a particular instructional strategy, they do provide an overview and suggest some directions for future research. A number of implications can be drawn upon which to build a picture of the effective science classroom, which we will discuss later. Upon closer analysis, these quantitative results agree fairly consistently with the qualitative summaries of research on instruction that have been reported in the science education literature (13, 17).

Inquiry-teaching and learning have been prevalent aspects of the science education literature of the past quarter century. The results of four meta-analysis studies point to positive results from inquiry teaching (2). Separate meta-analysis studies of elementary and secondary science curriculum projects found the use of curriculum materials developed with an inquiry philosophy to be more effective in enhancing student performance than most critics were willing to admit. Student achievement scores, attitudes, and process and analytic skills were either raised or greatly enhanced by participation in the new science curricula. Wise and Okey, in their analysis of instructional strategies, found an increase in cognitive outcomes when the inquiry-discovery strategy was used in science classrooms (21). In a study of the effects of inquiry teaching compared with inductive and deductive teaching approaches, positive support was given to inductive teaching strategies (12).

While the support for inquiry teaching and learning is not significantly conclusive, inquiry teaching appears to be a viable strategy that science teachers need to consider in any attempt to increase their effectiveness.

What does the research say about how an effective science classroom looks?

The effective science classoom is one in which instructional objectives are formulated and communicated to the students prior to the start of a unit of instruction. The objectives are carefully planned by the teacher and may have criterion-performance levels identified that are needed for mastery. Throughout the process of instruction for each unit, students receive feedback about their progress toward those objectives.

Teachers use set induction and advanced organizers to direct or focus attention to the lesson and provide connections between new learning and previous learning. These may take the form of questions that interest the student and that can be answered later in the lesson, or they may be short activities, demonstrations, or the presentation of familiar ideas that are related to what is to be learned. In effect, students are prepared for instruction either at the start of the unit or daily as a result of deliberate planning and actions taken by the teacher.

Students interact physically with instructional materials whenever possible through handling, operating, or practicing. Efforts are made by the teacher to provide greater realism or concreteness with the materials of instruction. Greater efforts are made by the teacher to incorporate use of manipulative and pictorial stimuli along with printed matter.

Teachers alter instructional materials or classroom procedures when they think that these alterations will increase the impact. For example, materials may be rewritten for clarity or reading level. Alternative reading materials may be provided for those students who have reading difficulty. Directions may be presented in other than written forms. Alterations occur as the result of deliberate action on the part of the teacher.

Greater attention is given by teachers to the types and placement of questions asked in the classroom. Attempts are made to ask fewer knowledge-level questions and to ask more questions requiring students to show that they comprehend, can apply, and can analyze what they have learned. Questions may be asked to cause students to hypothesize about what might happen, to make inferences about what is observed, or to apply what they have learned in a different context. The teacher asks questions throughout the lesson at appropriate times so that students attend to the instructional process. Yet, a barrage of questions is avoided. Questioning is part of the instructional plan. Teachers give students more time to respond to questions and wait longer before they act on a student's response. This action increases the length of student response, decreases the failure to respond on the part of students, increases the incidence of speculative thinking, promotes more student-to-student interactions, and causes more questions to be asked by students. In effect, the teacher bases verbal interaction with students on a plan that is formulated to yield desired results.

Greater use of formative (progress) testing techniques is made in conjunction with immediate or explanatory feedback, with possible remedial activities. Students select from a "menu" of remedial activities. Whether mastery learning has been adopted totally or not, some of the features of mastery learning will be utilized as part of a plan to assist students with their learning.

The effective science classroom reflects considerable teacher planning. More thought and care are given to maximizing learning outcomes. Teachers are aware of ways to utilize the time available in the classroom to increase the amount of academic engagement time (time-on-task) on the part of their students (5). Classrooms in science are better managed by the teacher. All of this reflects considerable effort and planning on the part of the teacher with the aid of the students.

Will science teachers still use lectures and recitation? Probably so. Will the textbook still be the key to new information, determining the sequence of instruction and what is learned? Probably so. But not to the extent revealed in studies of current practice. Lectures will be shorter, more interesting and meaningful; discussions more involved. A portion of the textbook will be read very carefully. The students will learn more and will find greater satisfaction in science classes.

The picture of an emerging effective science classroom is a vivid contrast to the typical or traditional classroom described earlier. In order to achieve it, science teachers need to realize that choices are available in terms of possible actions to take. Science teachers must make decisions in light of their own particular instructional context about how to proceed to implement an effective science classroom based on research evidence. The teacher is still the most important variable in the classroom (6).

Summary

A probable cause for students' failure to achieve in science classes is the use of teaching strategies that are text-based rather than learnercentered. Meta-analyses have shown that several teacher practices are associated with increased achievement. The use of pre-instructional strategies (set-induction, advanced organizers), the use of thoughtfully altered materials, and the use of more concrete experiences all lead to greater cognitive gains.

Research also indicates that the diagnostic remedial cycle, and the increase in time for learning, that is a feature of mastery learning leads to increased learning. Thus, specific strategies for teaching an instructional management system that permits feedback to students will lead to improvements in students' learning.

References

1. Aiello, N. C. and Wolfle, L. M. 1980. *A meta-analysis of individualized instruction in science.* Arlington, VA: ERIC Document Reproduction Service. (ED 190 404)
2. Anderson, R. D. 1983. A consolidation and appraisal of science meta-analyses. *Journal of Research in Science Teaching* 20: 497-509.
3. Bloom, B. S. 1971. Mastery learning. In *Mastery learning: Theory and practice,* ed. J. Block. New York: Holt, Rinehart, and Winston.
4. Boulanger, F. D. 1981. Instruction and science learning: A quantitative synthesis. *Journal of Research in Science Teaching* 18: 311-327.
5. Capie, W. and Tobin, K. G. 1981. Pupil engagement in learning tasks: A fertile area for research in science teaching. *Journal of Research in Science Teaching* 18: 409-417.
6. DeRose, J. V.; Lockard, J. D.; and Paldy, L. G. 1979. The teacher is the key: A report of three NSF studies. *The Science Teacher* 46 (no. 6): 31-37.
7. Dillashaw, F. G. and Okey, J. R. 1983. Effects of a modified mastery learning strategy on achievement, attitudes, and on-task behavior of high school chemistry students. *Journal of Research in Science Teaching* 20: 203-211.
8. Dunkleberger, G. E. and Heikkinen, H. W. 1983. Mastery learning: Implications and practices. *Science Education* 67: 553-560.
9. Glass, G. V 1976. Primary, secondary, and meta-analysis of research. *Educational Researcher* 5: 3-8.
10. Glass, G. V 1978. Integrated findings: The meta-analysis of research. In *Review of research in education,* vol. 3, ed. L.S. Shulman. Itasca, IL: F. E. Teacock.
11. Harms, N. C. and Yager, R. E., eds. 1981. *What research says to the science teacher,* vol. 3. Washington, D. C.: National Science Teachers Association.
12. Lott, G. W. 1983. The effect of inquiry teaching and advanced organizers upon student outcomes in science education. *Journal of Research in Science Teaching* 20: 437-451.