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ABSTRACT

Problem solving has long been a concern of science educators, with many asserting that problem solving should be both the overriding method and valued outcome of science instruction in American schools. This information bulletin synthesizes studies that deal with the relationships between the teaching of problem solving and secondary school science curricula. The first section of the document notes some of the inconsistencies in the use of terms related to problem solving and adds that rather than define problem solving, the process by which solutions are obtained are categorized and described instead. In addition to the term problem solving, other related terms used by some researchers and practitioners include scientific method, scientific thinking, critical thinking, inquiry skills, and science processes. The second section examines the large segment of the science education research which deals with problem solving as it relates to various aspects of instruction on students problem-solving abilities. The third major section focuses on the concern that some science curriculum developers have had with problem solving. A variety of science curricula are described, particularly as they relate to problem-solving skills. A final section discusses implications for instruction. (TW)

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The Relationship Between Curriculum and Instruction and Problem Solving in Middle/Junior High School Science

Problem solving has long been a concern of science educators. In reviewing 60 years of literature as represented by articles published in *Science Education*, Champagne and Klopfer (1977) noted that the first article in the first volume of the journal (then named *General Science Quarterly*) was written by John Dewey who said that "the method of science—problem solving through reflective thinking—should be both the method and valued outcome of science instruction in America's schools" (p. 438).

A clear link between science and problem solving was noted by Simon (1981): "... scientific discovery is a form of problem solving, and ... the processes whereby science is carried on can be explained in terms that have been used to explain the processes of problem solving ..." (p. 48).

Definition of Problem Solving

While there is agreement among science educators on the importance of the role of problem solving in school science, there is much confusion and inconsistency in the use of terms related to problem solving. Instead of defining problem solving, we have often tried to categorize and describe the process by which solutions are obtained. In addition to "problem solving," terms used include scientific method, scientific thinking, critical thinking, inquiry skills, and science processes (Champagne and Klopfer, 1981).

Careful attention was paid to process skills in the development of *Science - A Process Approach* (SAPA), which represented "an attempt to establish specific competencies in students which will make it possible for them to solve problems, to make discoveries, and more generally think critically about science ..." Gagne (1965, p.7). Gagne later said:

> Problem solving may be viewed as a process by which the learner discovers a combination of previously learned rules which can be applied to achieve a solution for a novel problem situation.
>
> Problem solving is not simply a matter of application of previously learned rules, however. It is also a process that yields new learning. (1977:155)

In what is essentially an operational definition, Shaw (1983) defined problem solving skills to include the four integrated science processes of interpreting data, controlling variables, defining operationally, and formulating hypotheses.

Hayes (1981) took an approach that is at once both simpler and more comprehensive:

> Whenever there is a gap between where you are and where you want to be, and you don't know how to find a way to cross that gap, you have a problem.
>
> Solving a problem means finding an appropriate way to cross a gap. The process of finding a solution has two major parts: 1. Representing the gap—that is, understanding the nature of the problem, and 2. Searching for a means to cross it. (p. i)

Problem Solving and Instruction

A large segment of the science education research dealing with problem solving is related to the effects of various aspects of instruction on students' problem solving ability.

Three studies examined the effects of classroom structure on student outcomes. Bowyer, Chen, and Thier (1976) studied the effects of a free-choice environment on sixth graders' (n = 90) ability to control variables. Half of the students were randomly assigned to a treatment group which had access to a Science Enrichment Center in which they could select a science activity of their choice along with their choice of materials. On a pretest, more than 60% of the students did not control variables, less than 32% controlled variables inconsistently, and an insignificant number controlled consistently. The program resulted in a significant change in the students' understanding of the necessity for controlling variables, particularly when the variables were familiar, such as weight and length.

McKee (1978) investigated the effects of two contrasting teacher behavioral patterns on science achievement, problem solving ability, confidence, and classroom behavior for students in sixth grade science. The teaching patterns were student-structured learning in science (SSLS), which minimized restrictions on students, and teacher-structured learning in science (TSLS), which was moderately restrictive. McKee concluded that the SSLS strategy functioned better to improve the problem solving skills of black students while working just as well for white students, and that the SSLS strategy was the obvious choice for teachers interested in promoting a student's ability to solve problems while improving self-confidence.

Creativity and the group problem solving process was studied by Fostor (1982) to determine whether cooperative small groups would stimulate the creativity of fifth and sixth grade students (n = 111) more than would an individualized learning environment. Half of the population worked by themselves, while the other half (experimental) worked together in groups of four or five. Each half worked in a student-structured environment on the same science activity which involved creating as many different types of electrical circuits as possible from a given set of batteries and bulbs. Among other things, it was found that both fifth and sixth graders in small groups did significantly better on creating electrical circuits than did individuals working alone.

A series of three studies examined types of instruction and problem solving. Egolf (1979) examined the effects of two modes of instruction on seventh and eighth grade students' abilities to solve quantitative word problems in science. Researcher-developed booklets were used to teach the students how to solve a specific type (density) of word problem and to teach a general method for solving word problems. Among the conclusions drawn were: (1) the booklets could be effectively used to teach students how to solve density problems; (2) no booklet successfully taught the students a general problem solving method; (3) significant grade level effects existed regarding word problem solving ability; and (4) student gender was not related to word problem solving ability.

A study to compare the effectiveness of mastery instruction to an equivalent non-mastery mode of instruction for improving junior high school students' learning and retention of selected science process skills was conducted by Brooks (1982). The process included lower levels of observation, classification, and prediction, and the higher level skills of data analysis and hypothesizing. While mastery instruction did not result in greater achievement gains, the evidence suggested that the mastery instruction strategy may result in a more permanent mastery of the higher process skills than would an equivalent time, non-mastery instructional strategy.

Novak, Gowin, and Johansen (1983) explored the use of the concept mapping and knowledge Vee mapping with seventh and eighth grade science students. They found that (1) in general, students of any ability could be successful in concept mapping and that other factors (e.g., motivation) were more important; (2) both seventh and eighth graders could acquire an understanding of the Vee mapping technique and apply it in regular junior high school science; and, importantly, (3) the experimental classes demonstrated superiority in problem solving performance on novel problems after less than six months of instruction with these strategies. The data suggested that concept mapping and Vee mapping were helpful with respect to changes in student knowledge about science and problem solving skills, and performance on novel problem solving tests. But the data also indicated that effective use of the Vee mapping strategy takes time for students to acquire and that two or more years may be required for students to achieve high competence.

Three studies involved various applications of technology in problem solving instruction. The effectiveness of two methods of instruction in teaching selected problem solving behaviors to sixth grade students was studied by Walker (1972). The problem solving behaviors were: observing, comparing, classifying, interpreting, analyzing, making assumptions, summarizing, critical thinking, and an example of problem solving. Two treatments, one visual and one auditory, were administered to two treatment groups; the control group received no treatment. No significant differences were found for experimental or control groups in any combination of comparisons.

A study to determine the effectiveness of televised instruction as an aid in changing attitudes toward problem solving was reported by O'Brien (1973). The study attempted to find whether fifth and sixth grade students, in urban and rural settings, would demonstrate significant differences in: (1) attitude toward the nature of problem solving, (2) self-confidence in solving subsequent problems, and (3) responsibility for success in problem solving. Televised instruction was found to be modestly successful in the urban setting, but regular classroom instruction was superior in changing attitudes in the rural setting. Participants in on-going activities in subject matter areas provided better continuity in control classrooms, thus facilitating attitude change. The television sessions may not have been conducted over a long enough period of time to measurably change attitudes.

Cox (1980) studied seventh and eighth graders' use of selected problem solving skills using microcomputers. Cox concluded, among other things, that: (1) students can improve in problem solving skills in a short time on a microcomputer; (2) the training program on organizing data in a matrix was successful; (3) individuals worked better in teams than alone; (4) the influence of group interaction enabled subjects of all abilities to successfully participate and solve problems; (5) all subjects adapted quickly and easily to the use of microcomputers; and (6) the microcomputer can be considered a viable and motivating aid for the development of some problem solving skills of early adolescents.

Six studies dealt with inquiry and problem solving strategies of instruction. Butts and Jones (1966) studied the effectiveness of inquiry training in producing more effective problem solving behavior in sixth grade students. The investigators concluded that students could benefit from directed instruction in problem solving behaviors and that age, IQ, sex, and science factual knowledge were not significant factors in inquiry training. The assertion that meaningful concept development results from inquiry training could not be supported; children who were successful problem solvers on the Tab Inventory of Science Processes could not apply the concept to a different situation.

A study was conducted by Davis (1979) to examine the effects on achievement of upper elementary school students of using two approaches to science instruction: (1) an expository-text, and (2) a guided inquiry-discovery. In the expository-text approach, the students received direct presentation of information and concepts from the text and teachers. In the guided inquiry-discovery approach, the students, guided by the materials and teachers, engaged in investigations involving inquiry processes structured to develop information and concepts. Based on the results of the study, it appeared that the guided inquiry-discovery method of instruction provided a means of combining the products and processes of science while enhancing positive attitudes.

Using different patterns and amounts of instruction on planning experiments with sixth and eighth grade students, Padilla, Okey, and Garrard (1984) examined the effects of instruction on integrated science process skill achievement. Among other things, it was found that (1) both sixth and eighth grade students can learn to use certain integrated process skills. (2) growth was apparent in identifying variables and stating hypotheses, and (3) greater benefit to students seemed to result from integrating science content and process instruction over a longer period of time.

An instructional program based on expert-novice differences in experimental problem solving performance was taught to sixth grade students by Ross and Maynes (1983). Based on a chronological account of what successful scientists do when designing an experiment, two skills, (1) developing a focus for the investigation (hypothesis formulation), and (2) establishing a framework for the investigation (including control of variables), were included in the instructional design. It was found that treatment condition students consistently outperformed control group students. The investigators concluded that the instructional program had a beneficial effect.

Lawsiripaiboon (1983) examined the effects of a problem solving strategy on ninth grade students' (n = 423) ability to apply and analyze physical science subject matter. The problem solving group received problem solving laboratory activities and classroom discussions emphasizing the application and analysis levels (as described in Bloom's *Taxonomy*). The conventional group received laboratory activities and discussions focusing on the knowledge and comprehension levels. It was found that the problem solving group significantly outperformed the conventional group, and that teachers in the problem solving group asked significantly more high level questions. The investigator concluded that the problem solving strategy used in the study seemed to be an effective means for improving overall achievement, particularly achievement at the application and analysis levels.

A similar study was reported by Russell (1979), Russell and Chiappetta (1980, 1981), and Chiappetta and Russell (1982). The purpose of the study was to improve eighth graders' ability to apply and analyze earth science subject matter. The experimental groups received a problem solving form of instruction which included reading, problem solving tasks, and discussion and laboratory exercises emphasizing application and analysis levels. The control groups received a traditional textbook oriented form of instruction which included reading, discussion, and laboratory activities. It was found that (1) the experimental group significantly outperformed the control group, and (2) teachers in the experimental group used a significantly higher level of questions. The investigators concluded that an instructional program using a problem solving approach will significantly increase overall achievement, particularly achievement at the application and knowledge levels, and that such an approach should include written problem solving activities and teacher directed questions that emphasize application of knowledge.

The Suchman Inquiry Development Program was used in three studies. Jones (1983) investigated what effect acknowledging successful autonomous discovery had on seventh grade students' problem solving abilities. concept development, science achievement, and self-concept as a learner when they were exposed to materials from the Inquiry Development Program for a semester. The same materials and techniques were used for both experimental and control classes with the exception that in the experimental class successful autonomous discovery was acknowledged by such comments as "right," "ok," or, "that agrees with what most scientists believe at this time." Jones concluded that acknowledgement or lack of acknowledgement of successful autonomous discovery by seventh graders did not significantly affect their self-concept as learners in relation to motivation, task orientation, problem solving, or class membership. Not acknowledging successful autonomous discovery resulted in greater science achievement gains than did acknowledgement. Exposure to either technique (acknowledging or not acknowledging autonomous discovery) appeared to significantly increase the problem solving abilities of the students. Neither technique resulted in a significant change in science concept development. This suggests that it was the student's discovery **activity**, rather than its acknowledgement, that was the important factor.

An investigation of the effects of intensive instruction on the ability of ninth grade students to generate written hypotheses and ask questions about variables pertaining to discrepant scientific events was reported by Pouler (1976) and Pouler and Wright (1977). The experimental instruction involved watching a discrepant event (a Suchman filmloop) until six acceptable hypotheses were written. The hypotheses were then evaluated by the investigator according to standards that reflected the type of reinforcement and instruction the student was to receive (e.g., the student might be told that the hypothesis was excellent and told the criteria for an acceptable hypothesis). It was found that reinforcement was essential for producing a greater quantity of written hypotheses. For higher quality hypotheses, reinforcement plus knowledge of the criteria was superior to no instruction.

In a related study, Wright (1978) examined the feasibility of intensive instruction in either the observation of details or hypothesis generation, using a discrepant event filmloop, as a model for improving the open exploration skills of ninth graders. In general, the treatment groups were superior to the control group in number of details reported, number and quality of hypotheses generated, and in number and diversity of questions asked. Wright concluded that both treatments were equally effective in improving the open exploration skills of the students, with the exception of the number of observed details, in which case the subjects who had been instructed in observing details exhibited superior performance.

The next two studies were part of a series of separate but coordinated meta-analyses of science education which analyzed some 250 studies involving more than 50,000 students (Anderson et al., 1982; Anderson, 1983). Four basic steps are involved in the use of meta-analysis: (1) reviewers first locate studies of an issue, using clearly specified procedures; (2) the outcomes of the studies are characterized in quantitative terms; (3, as many features of the studies as possible are coded; and (4) statistical procedures are used to summarize findings and relate study features to study outcomes (Kulik, 1983, p. 957). The statistical procedure in meta-analysis involves calculating a common measurement for each defined variable within a study. This common measurement is called an "effect size." Thus, for example, effect size measures the difference in performance of two groups on a dependent variable such as problem solving, achievement, or student attitudes (Kyle, 1984, p. 9). This allows conclusions to be drawn from many studies based upon this common measurement.

The potential for improving science instruction by altering teaching was reported by Willett, Yamashita and Anderson (1983) as a result of their meta-analysis of 130 studies of various teaching systems. The most successful systems appeared to be mastery learning and the personalized system of instruction (PSI). For the three outcomes of science methods, critical thinking, and logical thinking, an average effect size of 0.29 was found in favor of the instructional system over traditional approaches. The mean effect size produced over all systems was 0.10, indicating that, on the average, an innovative teaching system in this sample produced one-tenth of a standard deviation better performance than did traditional science teaching (p. 404).

Wise and Okey (1983) examined the effects of various science teaching strategies on achievement. Teaching methods were defined as being narrower, less encompassing than instructional systems; thus, teaching methods referred to limited aspects of a teaching plan. Twelve categories of teaching techniques were defined: audio-visual, focusing, grading, inquiry, manipulative, modified, presentation approach, questioning, teacher direction, testing, wait-time, and miscellaneous. "The main effect size overall was 0.34. Thus, for all samples considered the experimental science teaching techniques on the average resulted in one-third of a standard deviation improvement over traditional techniques" (p.419). Based on an effect size analysis of teaching strategies:

> The effective science classroom appears to be one in which students are kept aware of the instructional objectives and receive feedback on their progress toward these objectives. Students get opportunities to physically interact with instructional materials and engage in varied kinds of activities. Alteration of instructional material or classroom procedure has occurred where it is thought that the change might be related to some plan, such as the

cognitive level or positioning of questions asked during a lesson. The effective classroom reflects considerable teacher planning. The plans, however, are not of a "cookbook" nature. Students have some responsibility for defining tasks (p. 434).

Finally, Curbello (1984) conducted a meta analysis of 68 experimental studies, producing a pooled sample size of 10,629 students, to determine the effects of problem solving instruction on science and mathematics student achievement. The author concluded that:

1. When groups of students were given instruction in problem-solving, their achievement exceeded students not provided with instruction in problem-solving by an average of 0.54 standard deviations.
2. The duration of instruction in problem-solving is positively correlated with performance on problem-solving measures.
3. The most effective duration for instruction in problem-solving appears to be 5 to 10 weeks.
4. Problem-solving can be taught effectively in any topical area in science and mathematics.
5. The inquiry method seems to be one of the most effective strategies for teaching problem-solving (p. 78).

Science Curricula and Problem Solving

In tracing the historical development of problem solving as a curriculum goal, White (1978) noted that it has received attention as a major curriculum strand from the Dewey School of 1896 to the 1970s. Concern with problem solving among science curriculum developers has persisted into the 1980s.

Junior high school science curriculum developments in the 1960s abandoned traditional methods as well as traditional objectives. The new objectives were directed toward the development of the ability to solve problems in a logical manner. The relationship between inquiry teaching, as represented by the then newly developed science curricula, and intellectual development was studied by Friot (1971). Tasks described by Piaget and Inhelder were used to evaluate the development of inter-propositional logic, i.e., formal operations. The tasks were administered at the beginning and end of the 1969-70 school year to eighth and ninth grade students who were enrolled in science courses using the new science curricula. Control groups taking general science were evaluated at each grade level. The study showed that logical thinking processes could be evaluated using the Piagetian tasks, and that some curricula were effective at some grade levels but not at others. It was also found that sex and IQ were not significantly related to gain in logical thinking ability.

Schlenker (1971) reported an investigation to determine whether a physical science inquiry development program achieved significantly different results than did a traditionally-taught program using similar science content when taught to pupils in grades five through eight. Specific objectives for which comparisons were made were: pupil understanding of science and scientists, fluency and productivity in using the skills of inquiry or critical thinking, and mastery and retention of knowledge of the usual content of elementary school science. Schlenker concluded that children who studied under the inquiry development program developed a significantly greater (1) understanding of science and scientists, and (2) fluency and productivity in using the skills of inquiry or critical thinking than did children who studied under the traditional program, and that there was no consistently significant difference in the (3) mastery or (4) retention of the usual content of elementary school science between students who studied under the inquiry development program and students who studied under the traditional program.

A study to compare selected aspects of two seventh-grade science programs, the *Interaction of Man and the Biosphere* (IMB), an experimental inquiry program, and *Science is Explaining*, the control program, was reported by Gudaitis (1971). From pretest to posttest on attitude toward science, students in the experimental program showed no significant attitude change while students in the control group showed a significant decrease in attitude; there was no significant difference in the mean gain scores between the two groups. For science process skills, the mean gain scores for students in both programs showed significant growth; however, there was no significant difference in the mean gain scores between the two groups. For critical thinking skills, the mean gain scores for students in both programs showed significant growth; students in the experimental group made significantly greater gains in critical thinking ability than did students in the control group.

Hill (1982) compared the effect of a *Human Sciences Program* module and traditional science classes on pupils' logical thinking skills and attitudes toward their science course. It appeared that the *Human Sciences Program,* when compared to traditional science classes, was partially successful in promoting more positive attitudes. However, the *Human Sciences Program* did no more to promote logical thinking skills than did the traditional science classes.

Heffernan (1973) compared the effects of two methods of science instruction, individualized (ISCS) and traditional (New York State Science Syllabus), to determine whether there were differences in students' ability to (1) understand the methods and aims of science, (2) understand the scientific enterprise, (3) understand scientists as people, and (4) think critically, and whether there were differences (5) in students' attitudes toward science, and (6) in teacher behavior in the two types of classrooms. No significant differences were found between the two groups in understanding science, in critical thinking, or in attitudes to science. The data indicated that all the students involved in the study had positive attitudes toward science. The data also suggested that there may have been a "leak" of teacher behavior from the experimental to the control classes (in the form of an increase in group activity in the traditional class in response to its success in the individualized class).

A study reported by Stallings (1973) and Stallings and Snyder (1977), compared the inquiry behavior of ISCS and non-ISCS students, as measured by the Tab Science Test. No significant differences were found between ISCS and non-ISCS groups in the seventh or eighth grades; however, a difference in favor of the non-ISCS group was found in the ninth grade. No differences in patterns of clue questions selected were found between the ISCS and non-ISCS groups in seventh or eighth grade. Differences in clue question selection were found in the ninth grade, with the ISCS students exhibiting fewer inefficient patterns and more efficient patterns of inquiry than did the non-ISCS group. The ISCS program as used by teachers involved in this study did not result in clear gains in inquiry skills; however, the reliability of the Tab Test was found to be low, suggesting that caution be exercised in interpreting the results.

Evaluation of the *Unified Science and Mathematics for Elementary Schools* (USMES) program was the basis for studies reported by Shapiro (1973), Shann (1975), and Shann et al. (1975). A primary objective of the USMES program "is the enhancement of elementary school student's abilities in real, complex problem solving" (Shann et al., 1975, p. 127). Shapiro (1973) used the Notebook Problem to observe problem solving behaviors of students in grades two through six. The Notebook Problem consisted of presenting the students with three notebooks which differed from each other in such dimensions as number of pages number of lines per page, binding, price, etc. The pupils were asked to (1) select the most appropriate notebook for use in class, and (2) indicate the reasons for this selection. Shapiro reported that "the USMES experience had, irrespective of units and teachers involved, a marked and positive effect on the students' problem solving behavior" (p. 13).

During the 1973-74 school year, Shann (1975) evaluated the problem solving abilities of five students randomly selected from each of 38 classes which were using the USMES program. The students, working in groups of five, were presented with a catalog of equipment, cost data, and measuring instruments, and were asked to develop a plan for a playground which would serve students in their school. Two facets were measured: (1) behavioral assessment, which included motivation to accept the problem, commitment to the task, allocation of responsibility for manpower efficiency, and nature of group leadership; and (2) cognitive assessment, which included four summary rating scores on variable identification, measurement, calculation, and recording. On pretest-posttest comparisons, no significant differences were found (1) on the behavioral aspects; (2) on the cognitive factors of measurement, calculation, or recording; or (3) on product scores. On identification of variables, pretest scores were found to be significantly higher than posttest scores. Interviews with teachers disclosed that teachers perceived children in the USMES program to be more responsible for their own learning, and to show growth in data collection abilities, in graphing skills, in hypothesis testing, and in communication with their peers. Although not supported by the data, these perceptions were consistent and presistent among teachers from all geographic and demographic areas involved in the program.

The USMES program was again assessed during the 1974-75 school year by Shann et al. (1975) by evaluating students from 37 USMES and 34 control classes. The same behavioral, cognitive, and product scores were derived as in the earlier study. No significant differences were found for behavioral scores in either pretest-posttest or USMES versus control comparisons. A significant increase in cognitive scores was found across grade levels with higher scores associated with higher grade levels, but no significant differences were found between treatment and control groups. For product scores, no significant differences were found for either pretest-posttest or treatment versus control comparisons.

Bullock (1973) reported a study to determine the relative effectiveness of three different types of elementary school science curricula in the development of selected problem solving skills of sixth grade students. The three curricula were: *Science-A Process Approach* (SAPA), the Laidlaw textbook series, and the *Environmental Studies* (ES) project materials. It was found that: (1) there was no significant difference in the improvement of the problem solving skills of students using the Laidlaw textbook series compared to students using the SAPA curriculum materials; (2) there was a significant difference in the improvement of problem solving skills of students using the Laidlaw textbook series compared to students using the ES materials; and (3) there was a significant improvement in the problem solving skills of the students exposed to the SAPA materials compared to those exposed to the ES materials; and (4) significant improvement in problem solving skills was attained with both the SAPA program and the textbook series.

In a related study, the long term effectiveness of SAPA in the development of problem solving skills in fifth and sixth graders was assessed by Breit and Bullock (1974). This was a comparison of certain problem solving skills of children who had been in classrooms using the SAPA program for at least four years with the performance of children who had been in classrooms not using SAPA. A significant difference in problem solving skills was found in favor of the children who had been using the SAPA materials.

Shaw (1978, 1983) was concerned with determining the effect of the process oriented science curriculum, *Science-A Process Approach II* (SAPA II), on the ability of sixth graders to utilize problem solving skills which were defined as the integrated process skills of controlling variables, forming hypotheses, interpreting data, and defining operationally. Other areas investigated included: (1) determining if problem solving learned in science would transfer to social studies, (2) testing models concerning problem solving skills to determine if there was evidence for a hierarchy of problem solving skills, and (3) determining if training in problem solving skills would increase students' proficiency in basic skills such as observing, inferring, predicting, etc. The treatment consisted of 11 modules from SAPA II over a period of 24 weeks. The control groups participated in investigator-designed activities covering the same subject matter areas and incorporating the same amount of hands-on activities as the process modules. The treatment group scored higher than the control group on the problem solving skills portions of both the science and social studies instruments, indicating that problem solving skills can be taught by the process oriented science curriculum and that these processes will transfer to social studies content. No significant differences between the groups were found on either instrument for basic process skills except that the treatment group scored higher than the control group for the process of classifying on the social studies instrument, but not on the science instrument. Evidence was found to support the hierarchy model of process skills, suggesting that mastery of the basic skills is a prerequisite to proficiency in the problem solving skills.

The following three reports are all based upon meta-analyses of other studies and include findings related to other topics as well as to problem solving. The effects of new science curricula on student performance were studied by Shymansky, Kyle and Alport (1983), synthesizing the results of 105 experimental studies involving more than 45,000 students. In their analysis Shymansky et al. grouped 18 student performance criteria into six clusters: (1) achievement—fact/recall, synthesis/analysis/evaluation, general achievement; (2) perceptions—attitude toward subject, toward science, toward teaching techniques, toward self; (3) process skills—process measures/skills/techniques, methods of science; (4) analytic skills—critical thinking, problem solving; (5) related skills—reading, mathematics, social studies, communication skills; and (6)

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Patricia E. Blosser
Bulletin Editor

other areas—creativity, logical thinking (Piagetian tasks), spatial relations (Piagetian tasks). They found that:

> Across all new science curricula analyzed, students exposed to new science curricula performed better than students in traditional courses in general achievement, analytical skills, process skills, and related skills (reading, mathematics, social studies and communication), as well as developing a more positive attitude toward science. On a composite basis, the average student in new science curricula exceeded the performance of 63% of the students in the traditional science courses. (p. 387)

Science curriculum effects in high school were examined by Weinstein, Boulanger and Walberg (1980) in a meta-analysis of 33 studies involving over 19,000 students in the U.S., Great Britain, and Israel. The studies reviewed involved 13 different curricula, eight at the senior high school level and five at the junior high school level. Outcomes considered were: (1) conceptual learning; (2) inquiry skills; (3) attitudinal development; (4) laboratory performance; and (5) concrete skills. Weinstein et al. reported a ratio of approximately 4:1 in favor of outcomes related to the use of innovative curricula, and concluded that:

> . . . the post-Sputnic (sic) (1958) curricula produced beneficial effects on science learning that extended across science subjects in secondary schools, types of students, various types of cognitive and affective outcomes, and the experimental rigor of the research. Past reviews showed the percentage of positive results; but the present analysis shows a moderate 12 point percentile advantage on all learning measures of average student performance in the innovative courses (1980, p. J12).

Bredderman (1983) synthesized the research on the effectiveness of three activity-based elementary school science curricula (ESS, SAPA, and SCIS). Outcomes were measured in 57 studies, including over 900 classrooms. "The mean effect size for all outcome areas was 0.35. This indicates about a 14 percentile improvement for the average student as a result of being in the activity-based program" (p. 504). Gains for the activity-based curricula were found for science content, science processes tests, and affective outcomes. Gains were also reported, on the average, in creativity, intelligence, language, and mathematics. Disadvantaged students derived greater benefits than did other students. The effects of the particular programs reflected their relative curricular emphases (p. 499). Bredderman concluded that:

> The accumulating evidence on the science curriculum reform efforts of the past two or three decades consistently suggests that the more activity-process-based approaches to teaching science result in gains over traditional methods in a wide range of student outcomes at all grade levels (p. 513).

Implications for Instruction

Several of these findings have important implications for teaching science. A classroom in which students have some freedom of choice and control over events and in which they are permitted to work in small groups will be more effective in improving problem solving behaviors; this is also consistent with findings in mathematics education. Instruction in problem solving produces increases in achievement, and appears to be effective in any area of science. Clearly, inquiry experiences which involve designing experiments, controlling variables, collecting and interpreting data, are effective in promoting problem solving and result in increased conceptual learning when content and science process instruction are integrated. As the evidence in other areas has indicated, probably nothing is as effective as direct, hands-on, physical interaction with materials and equipment for promoting student achievement in both problem solving and science knowledge.

An examination of individual curriculum studies reveals mixed results. In most, but not all, cases using inquiry oriented curricula produced significant gains in problem solving skills as well as gains in attitudes toward science. These gains vary, however, from one curriculum to another and from grade level to grade level. Yet, when we consider the findings from the meta-analyses, which combine the results of many studies with thousands of students, we find convincing evidence that the curriculum does make a difference. In short, using a curriculum designed to promote an inquiry approach can result in enhanced problem solving abilities, as well as in gains in other outcomes.

As an example of material available for instructional applications, Costa (1985) has developed a sourcebook of materials for teaching thinking. Costa described a model of intellectual functioning which divides thinking skills into three areas. The first function is input, which requires gathering and recalling information. Examples of desired student behavior in this phase include naming, describing, identifying, and recalling in response to appropriate teacher questions. The second phase, processing, involves the students in making sense of the information they gathered. Desired student behaviors in this phase include making analogies, organizing, comparing, and contrasting. The final phase, output, requires the students to go beyond the concepts or principles they have developed and to use this relationship in novel or theoretical situations. Speculating, generalizing, evaluating, judging, and hypothesizing exemplify the desired student behaviors in this phase. Teacher behaviors that enable student thinking are then applied with this model of intellectual functioning. The teacher behaviors involve (1) questioning to help students collect and recall information, process the information into meaningful relationships, and apply the relationships in new or novel situations; (2) structuring the classroom to allow for individual, small group and total group interactions, managing resources to facilitate thinking; (3) responding to help students maintain, extend, and become aware of their thinking; and (4) modeling desirable intellectual behaviors in the classroom (1985:125).

It should be kept in mind that intellectual growth is a long term process. Most programs for teaching thinking suggest that two or three hours per week of carefully designed and implemented lessons are needed to permanently affect the cognitive abilities of students. It also appears that such an effort needs to be maintained for at least two years for mastery of these mental functions and should be integrated into the program rather than added on to it. Finally, as is clear from research in many areas, active learning has a positive effect on students' development of decision-making and problem solving skills, and their attitude toward school, teachers, the content to be learned, and learning itself (1985: 129).

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